

TP315
H34

DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH

FUEL RESEARCH BOARD

SPECIAL REPORT NO. 1

PULVERISED COAL SYSTEMS

IN

AMERICA

BY

LEONARD C. HARVEY

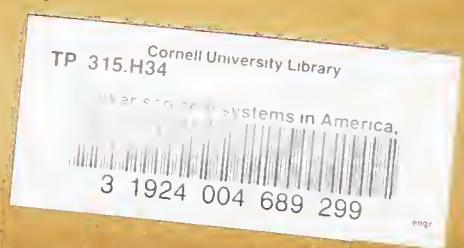
REVISED EDITION

LONDON:

PUBLISHED BY HIS MAJESTY'S STATIONERY OFFICE

1922

Price 5s. Od. Net



DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH

* Publications of the Department can be purchased through any Bookseller or directly from H.M. STATIONERY OFFICE at the following addresses:

IMPERIAL HOUSE, KINGSWAY, LONDON, W.C.2, and
28, ABINGDON STREET, LONDON, S.W.1;
37, PETEE STREET, MANCHESTER;
1, ST. ANDREW'S CRESCENT, CARDIFF;
23, FORTH STREET, EDINBURGH;

or from

EASON & SON, LTD, 40 and 41, LOWER SACKVILLE STREET, DUBLIN;

Copies can also usually be obtained from

Messrs. Horton's, Harrison Street, Johannesburg, South Africa,
and from

The Government Printer, Printing and Stationery Department, Wellington,
New Zealand.

Copies are not obtainable from the offices of the Department.

Deposit accounts may be opened at any of the Sale Offices of H.M. Stationery Office and orders placed in advance for the supply of all the Department's publications as issued. If certain categories only of publications are required, or if very expensive works should be excluded, this information should be clearly stated at the time of placing the order.

			Price	With	
			net	postage	
			s. d.	s. d.	
ANNUAL REPORTS OF THE DEPARTMENT					
Report of the Committee of the Privy Council for Scientific and Industrial Research for the year 1915-16.		(Cd. 8336)	0 3	0 4	
Ditto	ditto	1916-17.	(Cd. 8718)	0 3	0 4
Ditto	ditto	1917-18.	(Cd. 9144)	0 4	0 6
Ditto	ditto	1918-19.	(Cmd. 320)	0 6	0 8
Ditto	ditto	1919-20.	(Cmd. 905)	1 0	1 2
Ditto	ditto	1920-21.	(Cmd. 1491)	1 0	1 2

FUEL RESEARCH BOARD

Report of the Fuel Research Board on their Scheme of Research and on the Establishment of a Fuel Research Station. 1917	... ... ... ...	0 2	0 3
Report to the Board of Trade by the Fuel Research Board on "Gas Standards" (Cmd. 108). 1919	...	0 1	0 2
Report of the Fuel Research Board for the years 1918 and 1919	... ... ... ...	1 6	1 8
Fuel for Motor Transport. An interim Memorandum by the Board. 1920	... ... ...	0 3	0 4
The winning, preparation and use of Peat in Ireland. Reports and other documents. 1921	... ...	3 0	3 2

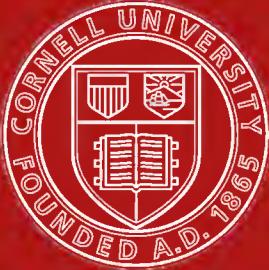
(Continued on p. iii of cover).

* A complete list of publications may be obtained upon application to the Department,
16 and 18, Old Queen Street, London, S.W.1.

5408



GENERAL VIEW OF COAL PULVERISING HOUSE AT A FRENCH COLLIERY (1921) SHOWING
DELIVERY PIPES FOR SUPPLYING PULVERISED COAL THROUGHOUT THE WORKS
(BERGMAN SYSTEM).



Cornell University Library

The original of this book is in
the Cornell University Library.

There are no known copyright restrictions in
the United States on the use of the text.

DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH

FUEL RESEARCH BOARD

SPECIAL REPORT No. 1

ERRATA.

Page 1, line 36 :

Prefatory note to the Second Edition:—for “September, 1918,” read
“April, 1918.”

Page 5. *Ash Troubles.* Line 2 :

for “some 150 tons” read “some 150 tons daily.”

Page 85, line 11 :

for “the latter plant” read “the former plant.”

(35845)

REVISED EDITION

LONDON :

PUBLISHED BY HIS MAJESTY'S STATIONERY OFFICE

1922

Price 5s. 0d. Net

DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH

FUEL RESEARCH BOARD

SPECIAL REPORT No. 1

PULVERISED COAL SYSTEMS

IN

AMERICA

BY

LEONARD C. HARVEY

REVISED EDITION

LONDON :

PUBLISHED BY HIS MAJESTY'S STATIONERY OFFICE

1922

Price 5s. 0d. Net

C O N T E N T S

	P A G E
PREFATORY NOTE by SIR GEORGE BEILBY, F.R.S. (Director of Fuel Research)	1
FOREWORD TO REVISED EDITION by THE AUTHOR ...	3
INTRODUCTION ...	9
Plan of Report ...	10
CHAPTER I.	
Conditions with pulverised Fuel ...	12
Notes on Range of Fuels suitable ...	13
Coke ...	13
Pitch ...	14
Anthracite ...	14
Bituminous Coals ...	15
Utilisation of Waste Coal ...	15
Lignites and Peat ...	16
CHAPTER II.	
Cost of Installation and cost of Powdered Coal ...	17
CHAPTER III.	
Standard Mill House Practice and Tabulated Answers given on Questionnaire Sheets sent to American Users of Pulverised Coal ...	22
CHAPTER IV.	
Transportation of Coal Dust to Burners ...	25
Note on Pulverised Coal Storage and Spontaneous Combustion ...	29
CHAPTER V.	
Feeders, Mixers, and Burners ...	32
CHAPTER VI.	
Applications ; Opinions of Users ; Working Results, &c. : Metallurgical and Similar Processes (Copper Smelting, Blast Furnaces, Basset Process, Lime and Fertilisers) ...	38
Open Hearth Steel Melting Furnaces ...	43
Heat Treatment and Soaking Pits ...	46
Continuous Billet Heating Furnaces ...	46
Heavy Forge Furnaces ...	47
Light Forge Furnaces ...	48
Piling, Bushelling and Skelp Welding Furnaces ...	48
Puddling Furnaces ...	49
Sheet and Pair Furnaces, and Annealing Furnaces ...	49
Malleable Iron Melting Furnaces ...	50
Rivet Heating and Nut Bolt Furnaces ...	53
Galvanizing and Tinning Furnaces ...	53
Steam Boilers ...	53
Railway Locomotives ...	68
Marine Propulsion ...	82
Domestic and Office Buildings ; Central Heating ...	83
CHAPTER VII.	
Conclusions ...	85
APPENDIX I.	
Systems investigated by the author in 1918 and New Systems ...	86
APPENDIX II.	
Installations visited by the author in 1918 ...	87
APPENDIX III.	
Pulverised Fuel Users ...	88
APPENDIX IV.	
Difficulties in the use of Pulverised Coal ...	94
APPENDIX V.	
Bibliography ...	95

PREFATORY NOTE TO THE SECOND EDITION BY THE DIRECTOR OF FUEL RESEARCH

Since its establishment in 1917 the Fuel Research Board has followed with interest the developments in the use of pulverised coal for industrial heating. In Great Britain this development has mainly taken place in connection with the Portland cement industry in which its use has largely superseded that of other forms of fuel. The special way in which heat is used in this case lends itself remarkably well to the utilisation of the best features of firing with pulverised coal, while it is little affected by the more doubtful or less advantageous features. The long flame which is so readily produced by pulverised coal can be fully utilised in cement kilns where it is not subjected to any considerable cooling effect. Although the lining of the kiln suffers from the action of the ash, the disposal of this ash causes no difficulty, for its presence in the final product of the cement kilns can be prepared for and accepted. No satisfactory method of utilising unground coal in a rotary kiln has so far been developed, and the expense of grinding must necessarily be incurred if direct application of the heat to the material is to be secured. For these reasons the experience of the Cement Industry is not in itself sufficiently complete to enable the method to be more widely applied without further study and enquiry.

At the time of the publication of the original report the only other experience of the method in this country of which the Board were aware was its use by the Admiralty on a limited scale for steam raising in certain forms of land boiler. Since then some experiments have been made on Locomotive Firing by the Great Central Railway Company, and one or two small power plants have been built. The progress made in this country, however, in the utilisation of pulverised fuel has been disappointing.

From the study of the most recent literature on the subject it was clear that the use of pulverised coal had during the past few years been taken up seriously and energetically in America, so that when the Board were approached on the subject by Mr. Leonard Harvey in March, 1918, they were prepared to assist him in making arrangements for his proposed visit to the United States for the purpose of investigating the whole position there as regards the preparation and use of pulverised fuel. Mr. Harvey was good enough to promise to keep in touch with the Board during his visit and to present to them a full report on his return to England. He reached New York in September, 1918, and at once began investigations, which were continued without a break for three months. Thanks to the introductions with which he was provided and to the generous help which was given him by the leading experts and the users of the method all over the United States, he was enabled to visit and investigate all the more important installations and to receive at first hand the experiences and views of the leading consumers of pulverised coal. The list of installations visited, which is given in Appendix II., shows how completely in this respect the purpose of his visit was carried out.

In June of last year Mr. Harvey forwarded a circular letter and questionnaire to a large number of users of pulverised coal in America with a view to collecting information in connexion with pulverised coal plants, par-

ticularly with regard to the results of running during the last few years. This enquiry met with a very cordial response, and the data which, thanks to the renewed help of American experts, Mr. Harvey has been able to collect, has been embodied in the revised edition. The use of pulverised fuel in America continues to extend, and the information forthcoming would seem to prove that its use in industry is being justified by results. Mr. Harvey also paid a short visit to the United States early in this year. Whilst there he was able to follow up several questions bearing on the use of pulverised fuel, the results of which are also incorporated in this edition.

After receiving and considering the revised Report and the more detailed explanations which Mr. Harvey has given at various interviews during the last two years, the Board have again come to the conclusion that the information obtained is of substantial value to the consumers of coal in British industries.

The Board believe that a further justification for publication and dissemination of both the original and the revised Report has been supplied by the recent developments in connexion with the coal industry. One effect of these developments will be to emphasise more than ever the need for the adoption of more economical and efficient means for the use of fuel in industry. The bare fact that the pulverising method is now being applied to the burning of between ten and fifteen million tons of coal per annum in America is in itself strong reason for its serious consideration in Great Britain. It is hoped that this consideration will not stop short of a close study of the possibilities which it may present of increased efficiency in the use of fuel in many British industries.

The advantages of the method as an almost perfect means of burning coal must be weighed against the cost of producing and handling coal-dust and the difficulties which may have to be overcome in dealing with its ash. These two sides of the technical and economic problem have been fully discussed with Mr. Harvey from time to time, and the whole subject has been critically examined from this point of view.

- It appears to the Board that the publication of the revised Report will enable the larger consumers of fuel to make a fairly complete preliminary study of the whole question and to decide whether, for their own particular requirements, a case can be made out for a closer and more exhaustive enquiry into its possibilities.

The Board, while they are satisfied that the enquiries have been carried out and reported on by Mr. Harvey in a conscientious and fair-minded way, cannot accept any responsibility for the statements and views expressed in the Report.

In conclusion, the Board desire to express to Mr. Harvey their appreciation of the way in which he has conducted these enquiries and their sincere hope that the sequel will show that it has been a work of real value to the Nation.

GEORGE BEILBY.

Fuel Research Board,

Department of Scientific and Industrial Research,

16 and 18, Old Queen Street,

London, S.W.1.

December, 1921.

FOREWORD TO REVISED EDITION.

(MARCH, 1921.)

Two years have elapsed since the compilation of the notes on Pulverised Fuel Systems in America which were published in the original report.

In revising the information already published and in bringing this subject up to date it has been considered best not to rearrange the chapters of the first report, but to effect alterations where necessary and to make addition of further data and records.

It is also thought advisable to refer briefly to recent progress made in England and in other countries outside America, which progress is resultant upon the pioneer work carried out in America and is due to the various systems developed in that country.

It is natural consequence upon the initial advance made in America that the greater amount of progress that has been made since the writing of the original report should still be found in America. That this should be so is in a great measure important and reassuring, for it shows clearly that the economies to be obtained by burning fuel in pulverised form have been further established by these extended applications in America.

An important step has been taken by the Government Railway Board of India in appointing Mr. W. A. C. Thorpe to make an investigation in America on the subject of pulverised coal as a fuel for locomotives. Mr. Thorpe has completed his work and his report is awaited with interest.

BOILER APPLICATIONS.

The most noticeable advance has undoubtedly been made in the direction of burning pulverised fuel under boilers. So important a decision as to instal this system at the new 200,000 k.w. Super-Power Station for the City of Milwaukee after thorough trial of this method as against mechanical stokers, a period of trial extending over two years, is conclusive evidence that pulverised coal firing for boilers is receiving strong support in America. Of so great importance is this departure from mechanical stoker practice for power stations that Mr. John Anderson's opinion and excerpts from his paper containing tests verified by independent experts have been printed herein.

Not only are the test figures for boiler operation given, but also actual detailed costs for operation and maintenance of the plant.

This information will be found on pages 61 to 68.

Many conclusive tests have proved that with the fine degree of pulverisation now adopted for standard practice the bulk of the ash contained in fuel is emitted from boiler-house stacks, but this has not been the cause of any complaints from residents in the neighbourhood of pulverised coal fired boiler plant. In metallurgical applications a far greater proportion of the ash is collected in the furnaces.

LOW VOLATILE FUELS.

In this connection also it will be of the greatest interest to note that fuels carrying as low as 5 per cent. of volatile combustible are now burnt successfully as boiler-house fuel by this method. Some notes on the utilisation of waste fuels having particular bearing upon accumulations of small and dust coal in South Africa are given on page 15.

CONTINENTAL INTEREST.

It is expected that great strides will be made in Europe in the use of pulverised fuel in view of the very high cost of imported coal.

On the Continent several installations of importance have already been made or are now on order for iron and steel works, and a great development is to be expected in the field of locomotive applications in Europe and foreign countries in the near future.

LOCOMOTIVE APPLICATIONS.

Experimental sets run on the Lehigh Valley Railway, U.S.A., the Great Central Railway, England, the New South Wales Government Railways, the Great Indian Peninsula Railway, and on the Brazilian and Swedish Government Railways have suggested possibilities of great importance if this method of firing locomotive boilers can be firmly established. Tests, which at the time were considered inconclusive, have also been carried out on the Swiss Federal Railway system.

Sufficient data is, however, available to warrant the application of pulverised fuel to railway locomotives when conditions are in accord with those necessary for success in relation to quality and price of fuel and type of locomotive in question.

Complete installations are now being supplied to the Netherland State Railways and Italian State Railways Authorities, with locomotive equipments as used on the Lehigh Valley Railway. These plants will be in operation by the end of this year (1921).

It is also interesting to hear that locomotive engineers from the west of America, where up to now oil has been the fuel almost exclusively employed, have inspected pulverised coal equipment in use with a view to conversion of oil fired locomotives to pulverised lignite and like fuel firing. This is owing to the difficulty of obtaining adequate supply of liquid fuel at a reasonable cost at the present time.

MARINE APPLICATIONS AND " COLLOIDAL " FUEL.

Little further progress has been made regarding the application of pulverised coal on board ships.

Interest is being taken in this project and developments which should prove successful for certain harbour and coastal ships are likely to take place in the near future.

The question of using pulverised coal and oil in combination as a "colloidal" oil is receiving support; Mr. Linden Bates, the originator of the mixture tested out on the "Gem" in America during the war, having disposed of his patents to an English company. An instructive paper read by Mr. Linden Bates in November, 1920, at a meeting of the Institution of Petroleum Technologists in London on this subject should be referred to for technical data. Mr. J. G. Robinson, chief engineer of the Great Central Railway, has accomplished a great deal in this direction, and an influential company has been formed to develop his patents. This class of fuel should prove of immense value for marine and locomotive work when supplies and prices of oil are again stable.

Two trans-Atlantic liners have been equipped for burning oil, and the London and North Western Railway Company have built a new type of locomotive fired in this manner. It is questionable whether there will be the requisite supply of straight oil for applications of this magnitude, but the substitution of colloidal oil will no doubt in time greatly assist in the development of this system of firing marine, locomotive, and land boilers, thus conserving 30 per cent. or 40 per cent. of liquid fuel supplies.

METALLURGICAL APPLICATIONS.

Additional information on this subject is given in the author's Iron and Steel Institute Paper, the inclusion of which in this report would only duplicate the source of reference.

Comment may be made on further progress accomplished in America.

Great interest has been taken in the results obtained with pulverised coal-fired reverberatory malleable iron melting furnaces and re-heating furnaces for corrugated iron work. Some notes on this subject are given on pages 50 to 53.

Some further work has been done in regard to using pulverised coal on blast furnaces for nickel, zinc and copper, by which means a reduction of up to 50 per cent. in consumption of coke has been effected. Following upon the successful results already obtained further experiments are in hand and authentic information should be available in the near future. Some notes on this subject appear on page 41.

The use of pulverised coal in the zinc industries has made progress. Apart from the encouraging experiments carried out in blast furnaces, it has been proved of advantage and economy for firing roasting regenerative smelting furnaces, showing a reduction over hand-firing of between 30 and 40 per cent. in fuel consumption, with increased recovery of zinc from the ore.

A brief note on the Basset process of obtaining liquid iron and steel direct from the ore in pulverised coal-fired furnaces is given under "Blast Furnaces," page 42.

ASH TROUBLES.

On the question of trouble from ash, it has been proved in Milwaukee, where some 150 tons of pulverised coal have been burned under power-house boilers, that whereas 70 or 80 per cent. of the ash content of coal is emitted from the stack no complaints have been received, and it is not known where the actual dust descends. The ash is of such a fine degree that until saturated with moisture it apparently remains in suspension in the atmosphere. Although the proportion of ash emitted from boiler-house stacks is admittedly heavy, it is of importance to note the opinion of Mr. Anderson on this subject of firing power-house boilers with pulverised fuel —see page 61.

In metallurgical work no trouble has been experienced during the process of rolling due to ash deposited on steel plate of the highest quality as used for motor body work.

PULVERISED COAL CONVEYING SYSTEMS.

Standard coal preparation and pulverising machinery remains practically unchanged, but much useful improvement has been made in methods for conveying pulverised coal.

Systems of conveying pulverised coal in bulk through trunk supply mains, by means of air suspension, are now in disfavour and are being replaced by safer methods, several explosions—some of a very disastrous nature—having taken place.

The practice of providing fuel storage at the furnace or boilers has therefore been definitely established as the most reliable means of ensuring continuous supply of fuel and a method which eliminates all danger of explosion in conveyor mains. It is, however, permissible to use short lengths of branch supply piping through which pulverised coal can be fed to burners by means of air suspension.

In consequence of these unfortunate experiences in America, great attention has been given to improvement of conveyor systems. The previously accepted safe method of conveying pulverised coal by means of screw conveyors has been superseded by the air-pressure system, or by the recently introduced pumping system.

With screw conveyors it has always been a difficult matter to find a convenient route and space for trestle construction on long or diverging lines of supply.

With the air-pressure or pumping system the pulverised coal is delivered through ordinary pipe work, which can be run underground or overhead in the same way as water or gas piping.

The proved success of these two systems has removed the value of the air-borne fuel distribution method, and has incidentally placed pulverised coal distribution and burning on a level of safety equal to gas or oil firing.

COSTS OF OPERATION.

As to actual working costs some figures are given in tabular form on the questionnaire sheet facing page 22, representing the result of questionnaire sheets sent out to users in America, but the authentic figures published in Mr. John Anderson's report (*Milwaukee Electricity Works*) and reproduced in this revised edition are of the utmost interest.

A table giving present-day cost of installations for different coal capacities per 24 hours, together with present-day operation expenses, is shown on page 18. This table can be taken as a guide as to approximate cost of complete plant and cost of operation, both calculations being based upon conservative figures.

CENTRAL SUPPLY DÉPÔTS.

No actual supply stations have been put down in England, although this object has been energetically advocated by a company formed to undertake such work. Adverse financial conditions prevented the erection in Bristol of a plant which it was hoped would have been commenced during the current year.

In America the Pacific Coast Coal Company continues to extend in this direction, having erected two further supply dépôts. Proposals are also on foot to inaugurate supplies in other American cities and one new company has commenced operations on these lines at Terre Haute, Indiana, supplying the pulverised coal in special canvas sacks.

LIME BURNING AND FERTILISER MATERIALS.

In view of the increasing importance of producing fertilisers for agriculture, some notes on results obtained at the present largest lime-burning plant in the world are given under applications, page 42.

NEW SYSTEMS AND PROCESSES.

When the writer was in the States in 1918, certain experiments were then in hand with a view to the fixation of gas from pulverised coal. That this matter is still receiving consideration is evidenced by several references to new types of plant devised for coking pulverised coal, the extraction of the light hydrocarbons, oil and gas, and the ultimate use of the "by product" coke in pulverised form.

Much work of an important nature is to be expected in this direction in the future. Some notes on the new Trent and Benner systems, the former developed under the auspices of the Bureau of Standards, Washington, are given below.

THE "TRENT" DISTILLATION SYSTEM.

Although the "Trent" System, which has been developed at the United States Bureau of Standards, Washington, is not essentially a pulverised coal system, yet it is very closely allied and may perhaps have some bearing upon the future use of fuel in pulverised form.

Mention of this Low Temperature Distillation process will therefore not be out of place in this Report. The fuel to be used is first ground in water to a fineness of 85 per cent. through a 200 mesh sieve. A quantity of oil is then added amounting roughly to 30 per cent. of the weight of the coal treated. It is claimed that this oil forms an "amalgam" with the coal dust, leaving behind practically the whole of the ash.

The resultant ash-free "amalgam" is then subjected to low temperature distillation in iron retorts for the purpose of recovering the added oil, together with a proportion of the volatile constituents of the coal. It is stated that a pure dry pulverised residue is obtained which contains some 6 per cent. or 7 per cent. volatiles and which is suitable for firing any type of furnace.

THE FIXATION OF GAS FROM PULVERISED COAL.

Many attempts have been made and continue to be made to use pulverised fuel in the making of "city" or "producer" gas.

One such attempt in America has recently met with a certain amount of success, and further developments are now in hand.

This process, worked under the "Benner" patents, has been favourably commented upon by Prof. J. W. Richards, of Lehigh University, and it is to be hoped that it will be successfully developed in due course.

In brief, the action is as follows:—

An ordinary gas producer is used as the generator. Pulverised coal is intermittently introduced into the hot zone at the top of the producer and the volatile constituents driven off. This portion of the gas produced is therefore rich in illuminants.

The carbonised dust falls on to the fuel bed in the form of coke and ash.

The supply of pulverised fuel is discontinued and steam applied to the coke bed to form water gas and to reheat the upper portion of the producer.

The resultant mixture of rich gas and water gas produces an industrial gas of some 375 or 400 B.Th.U.

Incidentally, it is claimed that total gasification of the carbonaceous constituents of any fuel is obtained, and the removal of the inert material in the form of ash or clinker can be readily accomplished.

The use of pulverised coal as a fuel for internal combustion engines has not yet been further developed, but this, the original intention of the late Mr. Diesel, may possibly be developed in course of time. A new type of internal combustion engine, the invention of an engineer of Montreal, Canada, is now being constructed with this end in view.

BIBLIOGRAPHY.

Through the courtesy and co-operation of Mr. Craver, Director of the United Engineering Society of New York, an extended bibliography covering recent literature on the subject of pulverised coal will be found on pages 95 to 117.

A considerable number of further references will be found in the writer's Iron and Steel Institute paper.

L. C. H.

PULVERISED COAL SYSTEMS

IN

A M E R I C A

BY

LEONARD C. HARVEY

INTRODUCTION

The general advantages* of pulverised fuel are summarised by Mr. F. P. Coffin, of the Research Laboratory of the General Electric Company, U.S.A., in the "General Electric Review" for May, 1918, as:—

1. Flexibility of control of fuel and air, and ability to extinguish the fire instantly.
2. Complete combustion even at high rate of burning, and elimination of smoke always assuming that the installation is properly made and operated.
3. Burning fuel in suspension eliminates the usual troubles which result from the formation of clinkers in the fire bed when coal is burned on grates.
4. Low-grade fuels may be burned efficiently regardless of the proportion of ash, sulphur or other impurities. When low-grade fuels are burned in grates, the capacity of the furnace is reduced in proportion to the percentage of incombustible content. This limitation does not hold when burning pulverised fuel in suspension, as the amount of ash in suspension in the flame at any one time is inconsiderable.
5. Very little excess air is required. This reduces the stack loss as well as the power required for the draught blowers. Less area is also required in flues and stacks.
6. Maximum fuel economy is possible in many applications.
7. The expense of supplying coal to scattered industrial furnaces is thereby reduced to a minimum. Pulverised fuel has semi-fluid properties; it flows easily and can be transferred through pipes:
 - (a) by screw conveyors,
 - (b) in a mass by means of compressed air,
 - (c) in suspension in a current of air.

It is clear that if these claims, or even a large proportion of them, can be substantiated in practice, this method of burning fuel is a question of first-rate national importance. In order that he might examine this

* See Chapter VI. for claims in respect of particular industries.

system at first hand, the writer of this report visited the United States in 1918, and he would here state that in his opinion the claims as set out above have been substantiated in practice.

Every assistance was accorded him while in America of obtaining facts and figures relating to the installations and systems, and he would pay a tribute to the American Government for the very energetic manner in which its Department of Fuel Economy is making every effort to conserve fuel, and to bring home to the industrial community the necessity for cutting down the wastage that has existed unchecked for so many years in nearly every plant using coal or other fuel.

The writer would also thank the Presidents, Directors and members of the firms visited in America for the open and friendly way in which they received his requests for information, and he wishes to record the fact that, without exception, every facility was given him to inspect the plants, question the operators, and obtain working data from the actual works' records.

He confesses that he never realised that in any country would it be possible for a stranger to receive so frank a welcome as was given him during his brief stay of four months in the United States of America.

The plan of the report is as follows:—

In Chapter I. are set out the principles underlying the process, and a short description is given of the plant.* This chapter also contains a discussion of the range of fuels which can be used by this method.

In Chapter II. an attempt is made to exhibit the economics of the system. Great difficulty has been experienced in this connection. The capital costs of existing plant of approximately the same size differ very widely, as do also the costs per ton of fuel produced. Tables are, however, inserted which have been prepared by the writer to conform with costs of machinery and material now ruling in England. It is hoped that these tables will be some guide to British engineers in arriving at a fairly close estimate of the probable costs both of installation and of operation of plant on various scales.

Chapter III. contains a description of standard mill house practice. This covers all processes from the reception of the coal to its delivery as powder from the mills. This part of the equipment does not differ much from the rival systems whose claims to superiority are in general based on the merits of their methods of distribution and application of the powdered fuel in the furnaces. These methods are considered in Chapter IV.

Burners form the subject of Chapter V.

One of the principal objects which induced the writer to visit America was to see for himself the actual applications of the various systems, and to obtain the opinions of users who have had substantial practical experience with them.

These opinions are collected in Chapter VI., which is divided into three sections:—

- (i) Metallurgical.
- (ii) Steam raising in stationary boilers.
- (iii) Locomotive practice.

A few remarks are also added concerning the use of powdered coal in ships and also its use for domestic purposes.

* Description of apparatus and equipment will be given in greater detail by the writer at the May meeting of The Iron and Steel Institute.

The principal criticisms which are made against powdered coal are:—

- (1) Liability to explosion.
- (2) Heavy accumulation of ash and slag.
- (3) Rapid deterioration of furnace linings.
- (4) Absence of proper control of flame and temperature within a furnace.

The first of these is discussed in Chapter IV, for it is in the distributing system, and in the storage system, if any, that the main danger is found. The writer is, however, satisfied that this danger has been exaggerated and that with reasonable precautions it becomes negligible.

The second of the difficulties cited above varies in gravity with the quality of the coal used and the nature of the work in which it is employed. No generalisations on the range of fuels available with this system are satisfactory, though it is quite common to find them in the advertisement literature. The question of grade of fuel and disposal of residual incombustibles has therefore been discussed in each of the three sections on applications which form Chapter VI. Similar treatment has also been accorded to the question of refractory linings and the control of flame and temperature.

For convenience of reference, the writer's conclusions are summarised in Chapter VII.

The various pulverised fuel systems are enumerated in Appendix I, and in Appendix II are given the names of the firms whose installations were visited by the writer.

Appendix III contains a list of pulverised fuel users which was compiled by the General Electric Company and published in the General Electric Review, Vol. XXI., No. 5 (May, 1918). This list has been slightly revised.

In Appendix IV. will be found some notes upon the subject of "Difficulties in the use of Pulverised Coal."

A short Bibliography forms Appendix V.

CHAPTER I.

The principles underlying the use of fuel in a pulverised form are set out with great clarity in the first of a series of unsigned articles on Powdered Fuel for Steam Raising, which appeared in the "Times" Engineering Supplement for February 22nd, 1918. The following is an extract from that article:—

"Combustion of fuel consists of two distinct processes:—(1) The distillation of the volatile hydro-carbons and their union with the oxygen of the air; and (2) the combustion of the remaining fixed carbon of the fuel. For the first process it is necessary to have a high furnace temperature so as quickly to drive off the hydrocarbons and also to have an adequate supply of air thoroughly mixed up with these gases in order to provide the necessary oxygen for combustion. Sufficient space must also be available in the furnace to allow the combustion process to be completed before the

gases come into contact with the cooling surfaces. For the second process it is necessary that the air supply be so arranged that every particle of fixed carbon is supplied with oxygen for combustion, and that the temperature is sufficient for the processes to be complete. It is probably true that for both these processes the most important item is the supplying of the correct volume of air and the thorough mixing of this air with every particle of the hydro-carbons and the fixed carbons.

"When ordinary fuel is being burnt, even with the latest automatic stoking and air-regulating appliances, it is exceedingly difficult to adjust the air supply correctly; and consequently the volume of air necessary, even in first-class boiler installations, is at least twice the amount which is theoretically necessary for perfect combustion. The loss thus caused is probably the greatest that takes place in the use of fuel in ordinary boiler installations.

CONDITIONS WITH POWDERED FUEL.

"In pulverised fuel plants the fuel is injected into the furnace in a very finely-divided state and is mixed in its passage to the furnace with the correct volume of heated* air. This mixture is injected into a chamber of suitable shape and volume, which is maintained at a high temperature. As each particle of fuel passes into the chamber the gases are immediately driven off, and for these, and the remaining particles of carbon, oxygen is available for immediate combustion; consequently, the process is so quick and the conditions so good that a high temperature is maintained and combustion considerably improved.

"It is interesting to consider the surfaces which are exposed with the fuel as ordinarily used and with the same weight of pulverised fuel. In the case of a piece of fuel 1 in. cube, the surface exposed is 6 sq. in. If, now, this cubic inch of fuel is pulverised so that each particle is a cube, the length of whose side is one-hundredth of an inch, the surface exposed by the whole of these small particles will be 600 sq. in. Further, each one of these particles will be surrounded with a supply of oxygen, and given a sufficient temperature and room the completion of the combustion processes is much better assured than with the piece of fuel 1 in. cube."

To obtain the fuel in this finely-divided form it is necessary to submit the coal to a somewhat elaborate process of crushing, drying and pulverising. The several operations of this process present no novelty. The coal as received is crushed in a breaker. It is then transported to a drier similar to that used for the calcining of cement, though in order to conserve the volatile constituents precautions need to be taken to ensure that no part of the coal reaches a temperature higher than 200° C. From the drier the coal passes to the grinder. At some point prior to the mill a magnetic separator is used to abstract any iron which may be present. From the mill the powdered coal is distributed, either mechanically by means of compressed air, or by mixing it with air moving at high velocity.

A detailed description of the necessary plant is given in Chapter III.

* The air is not usually heated.—L.C.H.

NOTE ON RANGE OF FUELS SUITABLE FOR USE IN PULVERISED FORM.

The range of fuels which can be used in pulverised form is such a very wide one that it is difficult accurately to set any limit. Coal must have a certain minimum content of volatile matter in order that it may ignite freely and that combustion may be maintained.

A coal high in ash must be considered purely from a commercial standpoint: whether it will pay to pulverise the heavy percentage of non-combustible, with consequent added wear and tear on the pulveriser, increased cost for power in relation to the actual heat-producing constituents of the coal powdered. These questions will be settled according to the price to be paid for the fuel and the purpose for which it is to be used.

The extent to which coal, which is at present being burned in its natural state as it comes from the mines, should be subjected to a preliminary process of carbonisation is at present receiving the serious attention of the Fuel Research Board of the Department of Scientific and Industrial Research, as well as of individual workers. At the present stage these enquiries have no very direct bearing on the adoption of pulverised fuel. The application of pulverisation to the solid products of carbonisation, coke and pitch may, however, be briefly referred to.

COKE.

Gasworks' coke, coke breeze or any other type of fuel containing less than about 10 per cent. of volatile combustible matter has until lately been considered unsuitable for use by itself in the pulverised form as a boiler fuel. If a fuel contains less than 10 per cent. of volatile combustible matter the deficiency can be made up by the admixture of pulverised coal rich in volatile combustibles. This is a matter which has to be considered in each particular case.

Apart from the fact that coke in powdered form is now burned in some cases in America, no actual data can be recorded.

The instance previously referred to, where, through shortage of coal, ash dumps at the engine cleaning pits were used in powdered form for firing boilers and other valuable evidence as to the successful burning of hard, low volatile anthracite, coal and washery slush, remove all doubt about the feasibility of disposing of coke breeze in this manner.

The case referred to where ash-dumps were used occurred at the shops of the Missouri, Kansas and Texas Railway, the ash being mixed with the coal available.

In a paper by S. W. Parr and C. K. Francis, on "The Modification of Illinois Coal by Low Temperature Distillation," the authors state that referring to the residue coke . . . "While much of the volatile constituent remains, it has undergone a change which makes it not difficult to carry on combustion without the production of smoke" . . . and . . . "Because of the very great ease with which this material may be broken down, it would require, in all probability, to be subjected to the briquetting process."

The chief difficulty to be encountered in the pulverisation of coke breeze is the excessive wear and tear of the pulverising mills when the coke is of a hard nature. The authors quoted, however, suggest that the

residue coke from the low temperature carbonising retorts can be maintained in such form that the material can be readily broken down. The fuel then becomes a valuable asset in this treatment of coal, the coke being a smokeless fuel of high carbon content.

The International Railway Fuel Association report that Pennsylvania anthracite waste tailings from Culm Banks has been used successfully under boilers without the addition of any bituminous coal. This fuel has also been used in locomotive fire-boxes, although the addition of bituminous coal is recommended in order to maintain ignition under the varying conditions of railway requirements. *Vide pp. 73, 78.*

The admixture of a small quantity of volatile bituminous coal to the coke breeze is a matter dependent upon the analysis of the coke. If anthracite culm of 8·30 per cent. content of volatile can be burned, straight, in locomotive fire-boxes, a by-product coke with a volatile content of 8 or 10 per cent., made in accordance with the object in view, should be a very useful fuel for burning under boilers or in metallurgical furnaces.

PITCH.

Hard dry pitch can be pulverised in certain mills adapted for the purpose. In some instances it has been recommended to run one or two mills in series rather than to attempt final pulverisation in one mill. The heat generated is the more readily dissipated in this manner.

A method of obtaining the powdered or granulation of pitch, to almost any degree of fineness, is by means of centrifugal force. The product is then in the form of minute spherical particles. This system has been recently brought out by the Barrett Co. who have also patented a special pitch burner.

ANTHRACITE.

There is now no difficulty experienced in burning anthracite coals in sufficient volume. For the smaller sizes of furnaces it may often become necessary to mix with anthracite a certain percentage of bituminous coal. This has also been found advisable for locomotive work owing to the limited area of the combustion chamber and the absence of any large body of hot refractory brickwork. At the 1917 Convention of the International Railway Fuel Association Committee upon this subject it was stated that:—

“The average annual output of the anthracite coal fields of Pennsylvania was, for the (5) five year period ending December 31, 1915, practically 70,000,000 tons. About 8 per cent. of this total output can be considered as waste, it being of such a nature that its satisfactory combustion, either in hand or stoker fired furnaces, is not possible. This waste culm or slush has the following general characteristics:—

Average Size.

- 2 per cent. through 5/16 round mesh and over 3/16.
- 8 per cent. through 3/16 round mesh and over 1/16.
- 90 per cent. through 1/16 round mesh.

Average Analysis—Dry.

Ash	...	...	...	...	24·00	per cent.
Volatile combustible	...	...	...	6·00	"	
Fixed carbon	...	...	...	70·00	"	
					100·00	"
B.Th.U.	...	...	...	...	11,500	

“The raw slush before drying will contain from 8 per cent. to 30 per cent. (and sometimes more) moisture. It can be seen from the above that this is not very attractive fuel for ordinary firing methods and burning on grates.

“The utilisation of this culm in pulverised form is, however, possible and practicable, and has been in use at a colliery in the Scranton district of Pennsylvania for about two years. Drying, pulverisation and handling is accomplished in the usual manner, the product averaging about 14 per cent. through a 100-mesh screen and 86 per cent. through a 200-mesh. No difficulty is experienced in handling, but the wear on the type of pulveriser in use is somewhat higher than when straight bituminous is being worked.”

Further tests carried out at the anthracite collieries in the Susquehanna district in burning washery slush were so successful that the whole boiler plant at Lykens and the new installation at Lytle have been arranged for burning this grade of “waste” fuel in pulverised form.

BITUMINOUS COALS.

There is no bituminous coal which cannot be burned in pulverised form. The ash content will be the determining feature as to whether a certain coal is to be recommended for any specific purpose, *but, broadly speaking, any bituminous coal with an ash content up to 30 or even 40 per cent. can very well be burned in this manner under suitable conditions with a loss of but 5 per cent. of the combustible matter.*

UTILISATION OF WASTE COAL.

By pulverisation much fuel now considered useless can no doubt be rendered serviceable in British Colonies and foreign countries. Information as to the accumulation of waste coal at colliery dumps in South Africa is given in the December, 1919, number of the “South African Mining and Engineering Journal.” The alleged disqualification of many South African fuels for locomotive use, moreover, can be overcome when the prospect of burning South African coal in pulverised form is considered.

The daily production of “waste” coal (if not the accumulations of past working) can no doubt be used if pulverised, and thus treated, the so-called low-heat-value coals of South Africa can be rendered serviceable for locomotive firing.

The coal used in Brazil is of lower quality than the South African fuels, as the following comparative analyses of Brazilian and South African coals clearly show:—

	Brazilian Coal, as used "dry" in pulverised form for locomotive fuel.	South African Coal. Undried.		
		Durban.	Kroonstad.	Dundee.
Moisture ...	7·90	1·73	1·6	8·29
Vol. carbon	28·04	9·50	27·10	31·27
Fixed carbon	34·73	61·50	60·05	45·32
Ash ...	29·33	28·27	11·25	15·12
Sulphur ...	3·16	9·1	1·51	1·43
B.Th.U. per lb.	8·820	10·177	12·950	11·020
Evap. power	9·2	10·4	13·4	11·4
	103·16	110·15	101·57	111·71
				102·37

In connection with these analyses of coals there are one or two points of outstanding interest. The Brazilian coal analysis represents the fuel in pulverised form after treatment in a rotary drier. The fuel is of friable nature, and the ash of such form that when subjected to heat it flows round the lumps of fuel on a hand-fired grate, rendering it impossible to burn the coal. Kroonstad coal contains about the highest degree of moisture recorded, 8·29 per cent., whereas most South African coal contains but 1 or 2 per cent. of water, for which drying plant would not be required.

Many references are made in the pages of the "South African Mining and Engineering Journal" to the friability of the fuel with consequent heavy loss in smalls and dust—a loss eliminated when coal is pulverised. In fact with air separator mills, coal containing 8 to 12 per cent. of moisture can be successfully pulverised, but care must there be exercised in storage and delivery.

LIGNITES AND PEAT.

These fuels in their natural state contain a heavy proportion of moisture, but lignites are being successfully dried for efficient pulverisation, and have been used on locomotives with very satisfactory results. While lignites can be burned on grates when used fresh after delivery, this fuel rapidly disintegrates and becomes a mere heap of fine dust when exposed for any length of time to the weather. In the disintegrated state it can neither be burned on mechanical stokers nor upon hand-fired grates. For the purpose of burning in pulverised form, it matters nothing whether the fuel has been freshly delivered or has been reduced to a state of dust by weather. In American lignite mines great care is exercised to prevent breaking up the lumps, and all the smalls are left in the mine; the amount of the latter sometimes reaches as much as 20 per cent.

As with lignite, the chief difficulty in the treatment of peat for rendering it suitable for pulverisation lies in the heavy content of moisture to be driven off before it can be properly powdered. Peat in its natural state

may contain 90 per cent. of water, so that it becomes necessary to dry it by air or mechanically before delivery to the mill house for final drying and pulverisation. Lignites and peat need not be dried to below 5 per cent. of moisture for efficient burning in powdered form. In fact, it is advisable not to dry lignite below this limit, otherwise the hydrogen and light gases in the fuel will escape to the stack before their combustion can take place in the furnace.

Without doubt the development of scientific investigation in the direction of peat utilisation in the form of pulverised fuel will disclose valuable industrial possibility in the near future.

Much work of this nature has been accomplished by the American Peat Society, and certain useful progress is recorded in the Journal of this Society published in January, 1921.

This record briefly states results obtained with peat mined by the Hennepin Atomised Fuel Co., Minneapolis, and pulverised at the Engineering Department of the University of Minnesota.

Hand fired coal converted 5 to 6½ lbs. of water into steam, per lb. of fuel, pulverised peat evaporating 9.9 lbs. of water. It was also proved that the pulverised peat gave approximately 90 per cent. of the efficiency obtained with pulverised coal; 105 lbs. of pulverised peat equalling 96 lbs. of pulverised coal.

The State Department estimate that there is a local supply of 6,558,000,000 tons of peat, or enough to last 1,000 years at present rate of industrial fuel consumption.

Peat mixed with bituminous coal has now been used in powdered form in locomotives on the Swedish State Railways for some years.

Straight peat-fired locomotives are in operation in Sweden.

Valuable records and test results have been recently published and extracts are herein reproduced on pages 75 to 77.

Notes given on page 8 regarding the "Trent" Distillation System should be read in conjunction with this chapter.

CHAPTER II.

COST OF INSTALLATION AND COST OF POWDERED COAL.

At the date of issuing the original report there was appreciable difficulty in giving accurate figures both for the cost of installation, and for pulverising and burning the fuel. Total costs for buildings, mill house machinery, powdered coal transport system, and burner equipment, will naturally vary for each and every plant. Reliable estimates for present-day cost of plant can now be given.

As to plant operation costs, much depends upon the size of the plant, how often or to what degree of continuity it is operated, the type of the mills adopted, facilities for handling the raw coal, the nature of the coal (whether in slack or lump form and whether soft bituminous or hard anthracite), and also upon the particular method adopted for supplying the powdered coal to the furnaces and burning it therein.

In order to give some fair idea as to the costs of plants for various capacities, and the relative costs for operating them, the figures set out in Table I have been based upon figures arrived at by the author and recorded

in his Iron and Steel Institute paper, May, 1918. The opportunity has been taken to revise these prices and costs in order to bring them more closely into line with material and labour costs which would prevail in England at the present time.

TABLE I.

Cost of Pulverising Plants and Cost of Pulverised Coal per ton (2,240 lbs.).

Daily Output in Tons.	Without Stand-by Plant.												With Stand-by Plant.												Daily Output in Tons.												
	Labour Cost per Ton.			Power Cost per Ton,			Dryer Fuel Cost per Ton, 20% of Coal Dried.			Repairs Cost per Ton.			Cost of Mill House Plant including Building.			Interest per Ton @ 8%.			Depreciation per Ton @ 10%.			Total Preparation Cost per Ton.			Cost of Mill House Plant including Building.			Interest per Ton @ 8%.			Depreciation per Ton @ 10%.			Total Preparation Cost per Ton.			
	s.	d.	s.	d.	s.	d.	s.	d.	s.	d.	s.	d.	s.	d.	s.	d.	s.	d.	s.	d.	s.	d.	s.	d.	s.	d.	s.	d.	s.	d.							
5	5	10	3	0	10½	4	3,500	2	9½	4	8	17	6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	5								
10	2	11½	2	10	10½	4	6,700	2	8	4	5½	14	1½	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	10								
15	3	11	2	10	10½	4	6,700	1	9½	3	0	12	8½	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	15								
20	2	11	2	10	10	4	9,300	1	9	2	10½	11	6½	10,300	1	11½	3	3	12	1½	20	—	—	—	—	—	—	—	—	—							
30	1	11½	2	10	10	4	9,300	1	3	2	1	9	3½	10,300	1	4½	2	3½	9	7½	30	—	—	—	—	—	—	—	—	—							
40	2	2	2	8	10	4	9,300	0	11	1	7	8	6	10,300	1	0½	1	9	8	9½	40	—	—	—	—	—	—	—	—	—							
50	1	2	2	8	10	4	11,100	0	10½	1	6	7	4½	12,700	1	0	1	8½	7	8½	50	—	—	—	—	—	—	—	—	—							
60	1	0	2	8	10	4	11,100	0	9	1	3	6	10	12,700	0	10½	1	5	7	1½	60	—	—	—	—	—	—	—	—	—							
70	0	10	2	8	10	4	11,100	0	7½	1	1	6	4½	12,700	0	8½	1	2½	6	7½	70	—	—	—	—	—	—	—	—	—							
80	1	1	2	6	10	3½	11,100	0	6½	0	11	6	2½	12,700	0	7½	1	1	6	5½	80	—	—	—	—	—	—	—	—	—							
90	1	0	2	6	10	3½	11,100	0	6	0	10	5	11½	12,700	0	6½	0	11	6	1½	90	—	—	—	—	—	—	—	—	—							
100	0	10½	2	6	9	3½	14,300	0	7	0	11½	6	0½	15,350	0	7½	1	0½	6	2	109	—	—	—	—	—	—	—	—	—							
150	0	7	2	6	9	3½	15,000	0	4½	0	8	5	3½	18,100	0	5½	0	9½	5	6	150	—	—	—	—	—	—	—	—	—							
200	0	5½	2	6	9	3½	20,000	0	4½	0	8	5	1½	25,500	0	3	1	0	5	6½	200	—	—	—	—	—	—	—	—	—							
250	0	6½	2	6	9	3½	20,000	0	4	0	6½	5	0½	25,500	0	5	0	8½	5	3	250	—	—	—	—	—	—	—	—	—							
300	0	5½	2	6	9	3½	26,100	0	4½	0	7	5	0	31,600	0	5	0	8½	5	2½	300	—	—	—	—	—	—	—	—	—							
350	0	4½	2	6	9	3½	28,300	0	4	0	6½	4	10½	32,000	0	4½	0	7½	4	11½	350	—	—	—	—	—	—	—	—	—							
400	0	5½	2	6	9	3½	28,300	0	3½	0	5½	4	9½	32,000	0	4	0	6½	4	11	400	—	—	—	—	—	—	—	—	—							
450	0	4½	2	6	9	3½	31,000	0	3½	0	5½	4	8½	35,500	0	3½	0	6½	4	10	450	—	—	—	—	—	—	—	—	—							
500	0	5½	2	6	9	3½	31,000	0	3	0	5	4	8½	35,500	0	3½	0	5½	4	9½	500	—	—	—	—	—	—	—	—	—							
550	0	4½	2	4	9	3½	32,000	0	2½	0	4½	4	5½	37,000	0	3½	0	5½	4	6½	550	—	—	—	—	—	—	—	—	—							
600	0	5½	2	4	9	3½	32,000	0	2½	0	4½	4	5	37,000	0	3	0	5	4	6½	600	—	—	—	—	—	—	—	—	—							
650	0	5	2	4	9	3½	32,000	0	2½	0	4	4	4½	37,000	0	2½	0	4½	4	5½	650	—	—	—	—	—	—	—	—	—							
700	0	4½	2	4	9	3½	35,000	0	2½	0	4	4	3½	41,000	0	2½	0	4½	4	4½	700	—	—	—	—	—	—	—	—	—							
750	0	5	2	4	9	3½	37,000	0	2½	0	4	4	4	42,500	0	2½	0	4½	4	4½	750	—	—	—	—	—	—	—	—	—							
800	0	5½	2	9	3½	43,000	0	2½	0	4½	4	2½	50,500	0	3	0	5	4	4	800	—	—	—	—	—	—	—	—	—								
850	0	5	2	2	9	3½	45,500	0	2½	0	4½	4	2½	53,500	0	3	0	5	4	3½	850	—	—	—	—	—	—	—	—	—							
900	0	3½	2	2	9	3½	48,000	0	2½	0	4½	4	0½	54,000	0	2½	0	4½	4	1½	900	—	—	—	—	—	—	—	—	—							
950	0	3½	2	2	9	3½	49,500	0	2½	0	4½	4	0½	55,200	0	2½	0	4½	4	1½	950	—	—	—	—	—	—	—	—	—							
1,000	0	3½	2	2	9	3½	53,500	0	2½	0	4½	4	0½	59,500	0	2½	0	4½	4	1½	1,000	—	—	—	—	—	—	—	—	—							

Figures given in this Table of Costs have been based on the following assumption :—

Labour at £4 per man per 44 hour week.

Power at 1½d. per K.W. hour and an average allowance of 20 K.W. hours per ton of coal pulverised and delivered to the exit of mill-house including Power for all operations.

Dryers to be fired with pulverised coal which is taken as 40s. per ton at the dryer burners ; an average allowance of 2 per cent. of the coal dried is made for dryer fuel assuming the moisture content of coal to be reduced from 15 per cent. to 1 per cent.

Yearly output is based on 300 working days.

It will be seen on reference to the graph Fig. 1, in which the corresponding values for coal at 20s. to 60s. are set out, that if one considers the value of a 25 per cent. reduction in fuel consumption and makes allowance for the cost of preparing, transporting and burning pulverised coal the areas representing nett savings for plants of small and large daily capacities are those shown between the horizontal line for price of coal per ton and the corresponding curves.

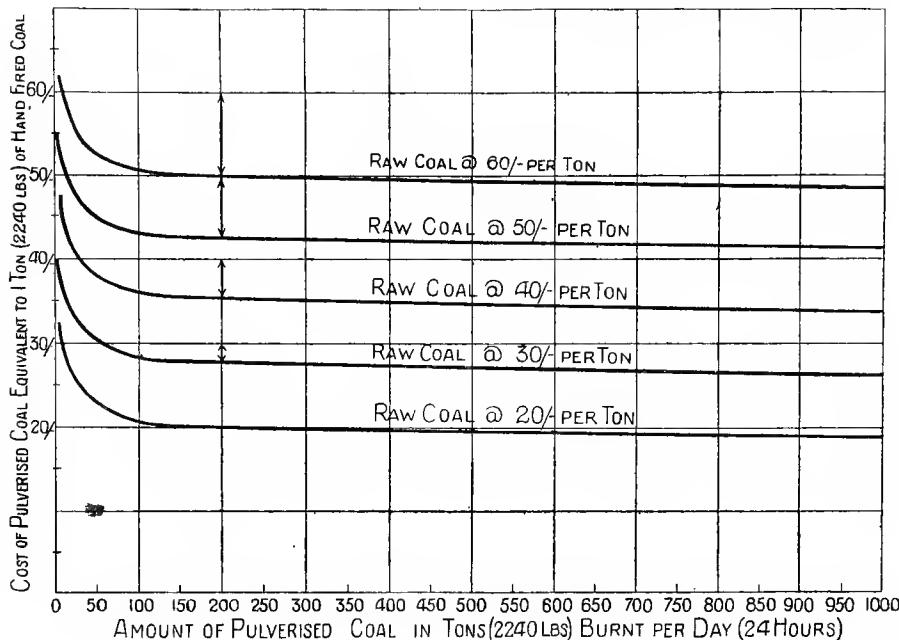


FIG. 1.—GRAPH SHOWING COST PER TON OF PULVERISED COAL FOR PERFORMING THE SAME WORK as 1 ton (2,240 lbs.) of hand fired coal, assuming a reduction of 25 per cent. by the use of pulverised coal and making allowance for all costs for preparation, etc., interest and depreciation on plant as set out in Table I.

Thus for 200 tons per 24 hours the "savings" as shown by the curves will be approx. :—

Coal costing 60s. per ton. ... Saving 10s. per ton as against hand firing.

"	"	50s.	"	..."	"	7s. 6d.	"	"	"
"	"	40s.	"	..."	"	4s. 9d.	"	"	"
"	"	30s.	"	..."	"	2s. 3d.	"	"	"
"	"	20s.	"	..."	"	0s. 0d.	"	"	"

(A reduction greater than 25 per cent. can often be made over hand firing practice and other economies; viz., reduction of labour, metal losses and increased output of furnaces, boilers, etc., have not been taken into account.)

In boiler and metallurgical work many valuable economies can be effected in the cost of production of steam or process output by the use of fuel in pulverised form, quite apart from the value of the actual saving in fuel used.

It must, therefore, not be forgotten that the introduction of pulverised coal carries with it many economies other than those applied to coal, the value of which in certain cases outweigh the actual value of the fuel saved.

The application of coal in powdered form also makes possible the use of fuels which for reasons stated elsewhere it may be impossible otherwise to consider.

The curves will suffice to indicate a conservative comparison between operating costs for raw coals at prices within the range of the graph.

Table II gives the number of pulveriser mills required for the tonnage capacities mentioned in Table I, and also shows the labour necessary in the mill house.

TABLE II.

Number of Pulveriser Mills Required and Mill House Labour.

Daily Output in Tons.	Output per Hour in Tons.	Number and Size of Mills.		Number and Size of Dryers.		Number of Men per Shift.	Labour Hours per Day.	Number of 8-hour Shifts per Working Day.	Maximum Output per Shift.	Approximate Output per Labour Hour.	Daily Output in Tons.
		Running Plant.	Stand-by Plant.	Running Plant.	Stand-by Plant.						
5	2½	Inches. 1-24	Inches. None	Tons. 1- 4	Tons. None	1	16	2	4	.31	5
10	2	1-33	"	1- 4	"	2	16	1	16	.62	10
15	2	1-33	"	1- 4	"	2	32	2	16	.47	15
20	2	1-33	1-33	1- 4	"	2	32	2	16	.625	20
30	2	1-33	1-33	1- 4	"	2	32	2	16	.94	30
40	2	1-33	1-33	1- 4	"	2	32	2	16	1.25	40
50	4	1-42	1-42	1- 4	"	2	32	2	32	1.55	50
60	4	1-42	1-42	1- 4	"	2	32	2	32	1.87	60
70	4	1-42	1-42	1- 4	"	2	32	2	32	2.19	70
80	4	1-42	1-42	1- 4	"	2	48	3	32	1.63	80
90	4	1-42	1-42	1- 4	"	2	48	3	32	1.87	90
100	6	3-33	1-33	1- 8	"	2	48	3	48	2.1	100
150	8	2-42	1-42	1- 8	1- 8	2	48	3	64	3.1	150
200	12	3-42	1-42	1-10	1-10	3	48	2	96	4.2	200
250	12	3-42	1-42	1-14	1-14	3	72	3	96	3.5	250
300	16	4-42	1-42	1-14	1-14	3	72	3	128	4.2	300
350	16	4-42	1-42	1-14	1-14	3	72	3	128	4.9	350
400	20	5-42	1-42	2-10	1-10	4	96	3	160	4.2	400
450	20	5-42	1-42	2-10	1-10	4	96	3	160	4.7	450
500	24	6-42	1-42	2-14	1-14	5	120	3	192	4.2	500
550	24	6-42	1-42	2-14	1-14	5	120	3	192	4.6	550
600	28	7-42	2-42	2-14	1-14	6	144	3	224	4.2	600
650	28	7-42	2-42	2-14	1-14	6	144	3	224	4.5	650
700	32	8-42	2-42	2-14	1-14	6	144	3	256	4.9	700
750	36	9-42	2-42	4-10	1-10	7	168	3	288	4.5	750
800	40	10-42	3-42	4-10	1-10	8	192	3	320	4.2	800
850	40	10-42	3-42	6-10	1-10	8	192	3	320	4.4	850
900	40	5-57	1-57	4-14	1-14	6	144	3	320	6.25	900
950	48	6-57	1-57	4-14	1-14	6	144	3	384	6.6	950
1000	48	6-57	1-57	4-14	1-14	6	144	3	384	6.9	1000

If the question of how much raw coal is used per ton of coal pulverised and burned in the furnace is considered, and the equivalent in coal for mine haulage and transportation to the power station and to the consumer is not taken into account, it is found that this amounts to about 6 per cent. of the weight of fuel consumed in powdered form.

This figure has been arrived at in the following manner. It is assumed that for one unit of electricity used 3 lbs. of coal are required.

Power in Milling House, 18 to 20 kw. hrs., per ton of coal pulverised.	
Say 20 kw. hrs. at 3 lbs. coal	... ... ... 60·0 lbs.
Fuel used in drier at 2 per cent.	... ... ... 44·8 "
Power for conveying coal-dust* at 2½ kw. hrs. per ton (screw conveyors)	... ... ... 7·5 "
Power for air supply for burning powdered coal	... ... 22·5 "
 Raw coal used per ton of pulverised coal	... ... 134·8 "
	or 6 per cent.

Some actual American working cost records were given in the original report. As, however, more accurate figures and estimates can now be introduced for present-day practice much of the previous data has been omitted in this issue.

Table III has again been reproduced on account of the division of operating cost figures, which are valuable as showing the proportion of costs to be borne by different departments.

TABLE III.

Detailed Costs for a Pulverising Plant of 80 tons capacity operating at 30/35 tons per day at 1918 values.

1917-18.	Labour 6-7 Men.	Labour Insurance.	Stores.	Electric Repairs.
	s. d. \$	s. d. \$	s. d. \$	s. d. \$
October ...	3 9·65 (0·913)	0 0·5 (0·01)	0 10·9 (0·218)	0 9·5 (0·190)
November ...	3 4·4 (0·808)	0 0·5 (0·01)	0 10·6 (0·212)	0 9·25 (0·185)
December ...	3 5·75 (0·835)	0 0·5 (0·01)	0 10·4 (0·208)	0 10·35 (0·207)
January ...	2 9 (0·66)	0 0·5 (0·01)	0 4·15 (0·083)	0 6·9 (0·138)
February ...	3 5·7 (0·834)	0 0·5 (0·01)	0 4·15 (0·083)	0 5·9 (0·118)
March ...	2 9·25 (0·665)	0 0·4 (0·008)	0 8 (0·16)	0 6·2 (0·124)

[Continued—

1917-18.	Machining Repairs.	Engineering Repairs.	Electric Power at 0·018.	Total Operating Cost per ton.
	s. d. \$	s. d. \$	s. d. \$	s. d. \$
October ...	0 6·95 (0·139)	— (0·00)	0 9·85 (0·197)	6 10·85 (1·657)
November ...	0 11·8 (0·236)	—	0 11·4 (0·228)	6 11·45 (1·669)
December ...	0 4·3 (0·086)	0 0·9 (0·018)	0 11 (0·220)	6 6·7 (1·574)
January ...	0 3·2 (0·064)	0 0·95 (0·019)	1 1·65 (0·273)	5 2·35 (1·247)
February ...	1 1·55 (0·271)	0 1·9 (0·038)	0 11·2 (0·224)	6 6·4 (1·568)
March ...	0 2·45 (0·049)	0 1·15 (0·023)	0 8·75 (0·175)	5 0·2 (1·204)

Average Total for six months 6s. 2d. (\$1·48) per ton of coal.

* Depending on distance.

*Costs for a 50-ton per day plant working at about 30 tons per day output,
also at 1918 values.*

	£	s.	d.	\$
Direct labour	75 18 8 (364·48)
Repairs, labour	138 13 3·5 (665·59)
Repairs, material	118 3 5 (567·22)
Supplies, waste, &c.	2 5 6 (10·92)
Insurance	4 15 6 (22·92)
On charges	100 3 10·5 (480·93)

Making a total for 928 tons of coal pulverised and delivered to the furnaces, £882 17s. 1d. (\$4,237·70) or 9s. 4·5d. (\$2·25) per ton. This was a month when charges for upkeep and repairs were heavy, the normal figure being about 5s. 11d. (\$1·42) per ton. Accepting this latter figure for eleven months of the year, the annual average would be 6s. 2·45d. (\$1·489) per ton.

In order to obtain up-to-date information from American users a questionnaire sheet was circulated (November, 1920), and the data obtained as to costs of operation, opinions and recommendations are given in the Tabulated Record of Answers facing this page.

CHAPTER III.

STANDARD MILL HOUSE PRACTICE.

It is not intended to detail the equipment of coal pulverising plants, but only to sketch out the general lines on which American installations are designed.

Raw Coal Handling.

Run of mine, lump coal, or screenings are delivered alongside the pulverising mill in railway trucks fitted preferably with bottom dumping doors. The trucks are brought over concrete track hoppers, protected at the top by grizzlies or open iron grids through which the coal passes into the storage hoppers.

If the storage hoppers extend for some considerable distance it will be necessary to use a belt traveller or other means of feeding from the hoppers to the preliminary crusher.

Preliminary Crusher.

A Jeffrey or other simple crusher is used to break down the coal to about $\frac{3}{4}$ inch mesh for convenient handling and for the efficient evaporation of moisture as the coal is passed through the drier.

First Elevator.

From the discharge of the crusher the coal is usually delivered direct into the elevator buckets, which raise the crushed coal to the top of the mill house, where the coal is carried along a short belt conveyor.

The speed of elevator delivery is regulated to the capacity of the crusher.

Magnetic Separator.

The belt conveyor passes over a magnetic pulley which removes tramp iron, pieces of pick heads, etc., from the coal. Sometimes an additional magnetic separator is placed before the crusher. This practice is only employed when coal deliveries are likely to contain heavy pieces of iron.

Missing Page

It is essential to remove all heavy pieces of iron before the coal is crushed, otherwise they will damage the rolls or teeth of the crusher. Small pieces of iron must be removed before they reach the pulverising mills. Mills fitted with screens for controlling the fineness of the coal dust are susceptible to damage from this source, for these pieces of iron are liable to pierce the mill screens and so destroy the uniform fineness of the product, and for this reason an efficient magnetic separator must be used.

Crushed Coal Bin.

From the magnetic separator the coal passes by gravity into the crushed coal storage bin of somewhat larger capacity than that required to feed the pulverising mills. This provision is usually made so that repairs to the crusher, due to broken teeth or rolls, can be carried out whilst the mills are kept going on the supply of crushed coal in the storage bins.

Driers.

From the crushed coal bin the coal descends by gravity into the driers.

Driers of several efficient types are in use. These are heated by means of hand-fired grates, mechanical stokers, or pulverised coal burners. The hot gases from the furnaces are sometimes passed directly over and in contact with the coal, or through a central tube to the end of the coal-drying cylinder, and thereafter returned along the outer space in contact with the coal; or again, a compromise is made between these two systems. For the latter case, the hot gases first come in contact with the outer shell of the drier to about half-way along its length; they are then collected and transferred to the end of the cylinder where they enter into direct contact with the coal as the gases pass back through the cylinder to the furnace end, where they escape to the drier chimney. As a rule, the driers are rated to comply closely with the maximum capacity of mills operating. Crushers are generally started up in advance of the pulverising mills, and are run for a short time after the mills are closed down. In this way a sufficient amount of dry coal is available when the mills are started up. Coal should be dried to within 1 per cent. moisture, about 10 per cent. moisture being extracted at each passage of the coal through the drier. When fuel contains a heavy percentage of water the coal can be passed through the drier a second time.

Second Elevator.

From the driers the dried coal is taken to the top of the building by the second elevator and fed into the dry coal bins.

Pulverising Mills.

Apart from the several makes of coal grinding mills used in the cement trade, the mills generally installed in American steel works are the "Fuller," the "Raymond," and the "Bonnot."

The Fuller Mills have not been supplied with air separator fans until quite recently. Without these the pulverised coal at the discharge spouts used to be carried to the top of the mill house by means of the usual type of bucket elevators. Present practice is to use the new system of pumping the pulverised coal through ordinary pipes by means

of the Fuller-Kinyon pump referred to in detail on page 28. The Raymond and Bonnot Mills are run in conjunction with air separator fans. The advantage of the air separation exhaust from the mills lies in the direct delivery of the coal dust to the pulverised coal bins without having to employ elevators. Air separation and delivery of coal dust by suction from the mills is more or less a matter of convenience. The total power required for grinding and delivery of the coal by air separation is somewhat greater than that required to run screen mills and bucket elevators or the pumping system. For air separation one can claim the advantage of simplicity of plant, absence of dust leakage through crevices in the mills, no dust leakage from the casing of the bucket elevator required with screen mills, and no repairs for this third elevator equipment.

On the other hand the coal dust must pass through the suction fan at high speed, and this has a rapid wearing effect on the fan wheel. It is also necessary to instal cyclone separators to deposit the coal dust from the air current. It is quite an open question as to which system should be adopted—many factors must be considered for each particular case. It will be noticed that air separation has been adopted for the Milwaukee Super Power Station plant, yet for another modern plant screen separator mills have again been preferred.

The advocates of air separation claim a greater uniformity of product with absence of coarse particles, which may occur with screen separator mills, due to damage of the screens by pieces of iron which have passed the magnetic separator.

On the other hand, a screen mill undoubtedly produces a greater proportion of very fine powder, called by some impalpable powder, which is of immense value in effecting the early ignition and ready combustion of pulverised coals.

In practice and so far as actual product is concerned either one or other system can be used with equally good results for all ordinary purposes of the steel and copper industries and for steam boiler plants.

That screen separator mill houses can be very dirty the writer knows from observation, but certain air separator mill houses inspected were no cleaner. Given intelligent and interested supervision there is no necessity to have dusty conditions with well-designed screen separator mill plants, but of course air separation is in effect "vacuum" withdrawal of the pulverised coal.

The standard of fineness that has been adopted throughout the United States for industrial coal dust plants is 85 per cent. through a 200 mesh screen (40,000 holes to the square inch), and 95 per cent. through a 100 mesh screen (10,000 holes to the square inch). Another argument which is advanced against the use of screen separation mills is that when the coal contains, say 4 or 5 per cent. of moisture, the screen clogs up and becomes inoperative. This is true to a certain extent, but then there should not be this moisture content remaining in coal to be pulverised in a screen mill. Coal as it leaves the drier for this purpose should not contain more than 1 per cent. of moisture. In cases where fuel, such as peat, cannot be dried to within, say 5 per cent. of moisture as it leaves the drier or for other reasons is not so treated, then it usually becomes a question for air separation. Lignite containing 13 per cent. moisture has been successfully pulverised in screen mills, but one would not install screen mills to operate under such conditions.

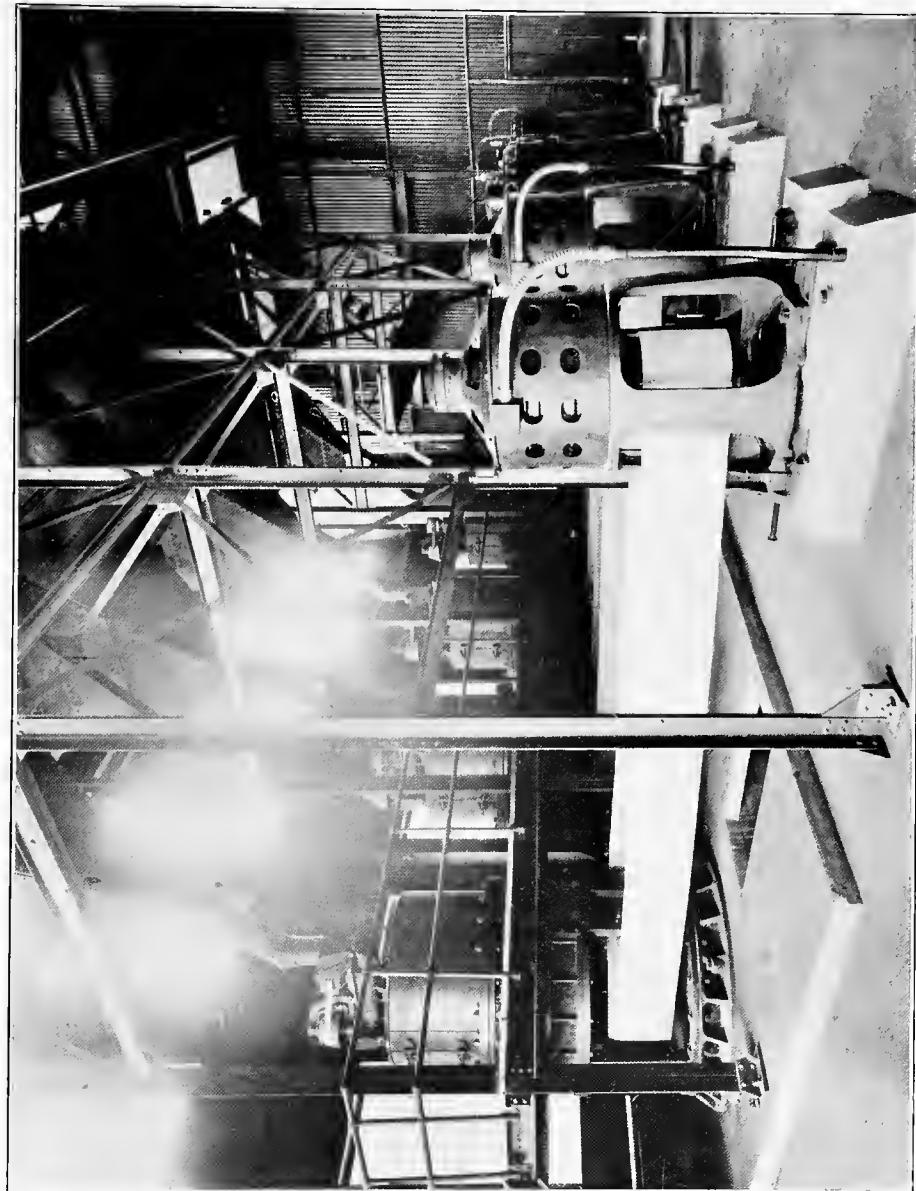


Fig. 2.—INTERIOR VIEW SHOWING FULLER-LEHIGH PULVERIZER MILLS. UNITED VERDE EXTENSION MINING COMPANY, JEROME, ARIZONA.

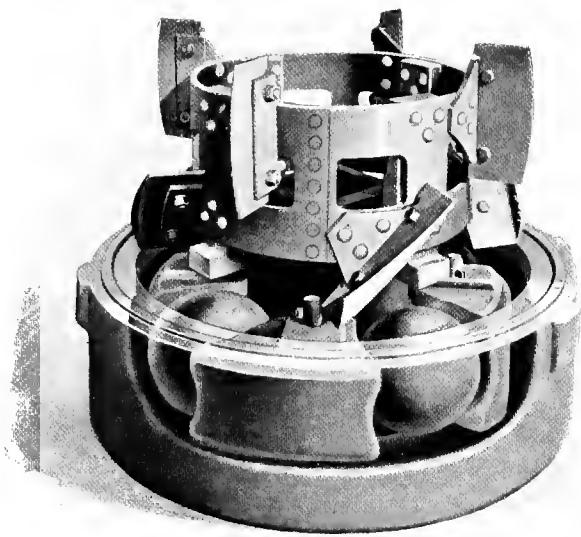


FIG. 3.—PULVERIZING AND SEPARATING ELEMENTS OF THE FULLER-LEHIGH PULVERIZER MILL.

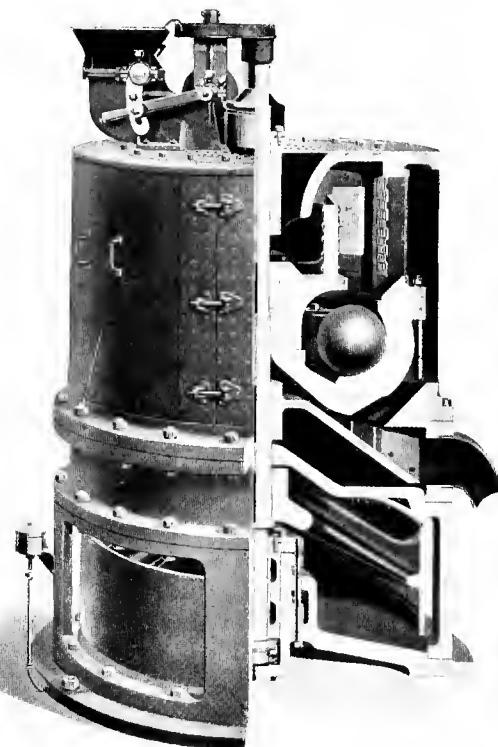


FIG. 4.—57" FULLER "DREADNOUGHT" MILL, FAN DISCHARGE TYPE—PULLEY DRIVEN.
(SCREEN SEPARATOR TYPE.)

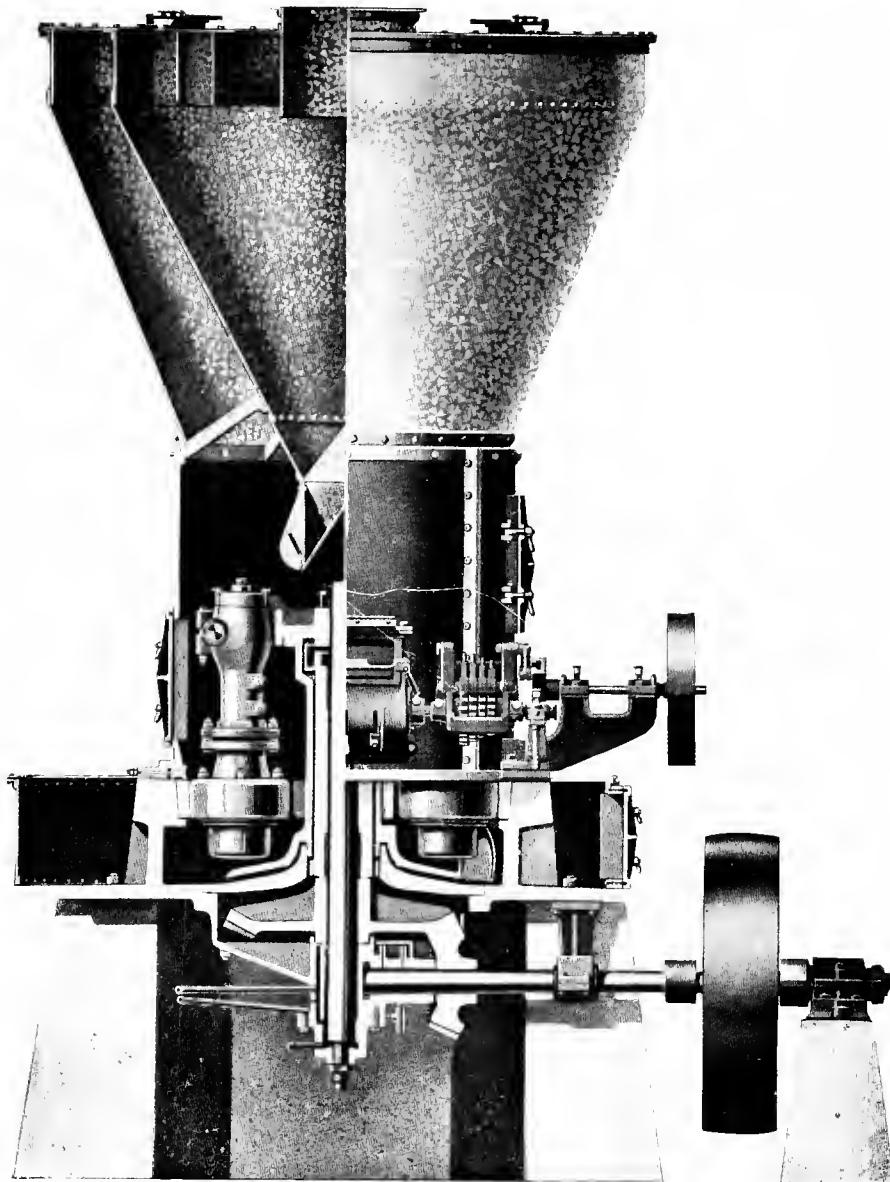


FIG. 5.—SECTIONAL VIEW OF RAYMOND HIGH-SIDE ROLLER MILL.
(AIR SEPARATOR TYPE.)

To face page 25.

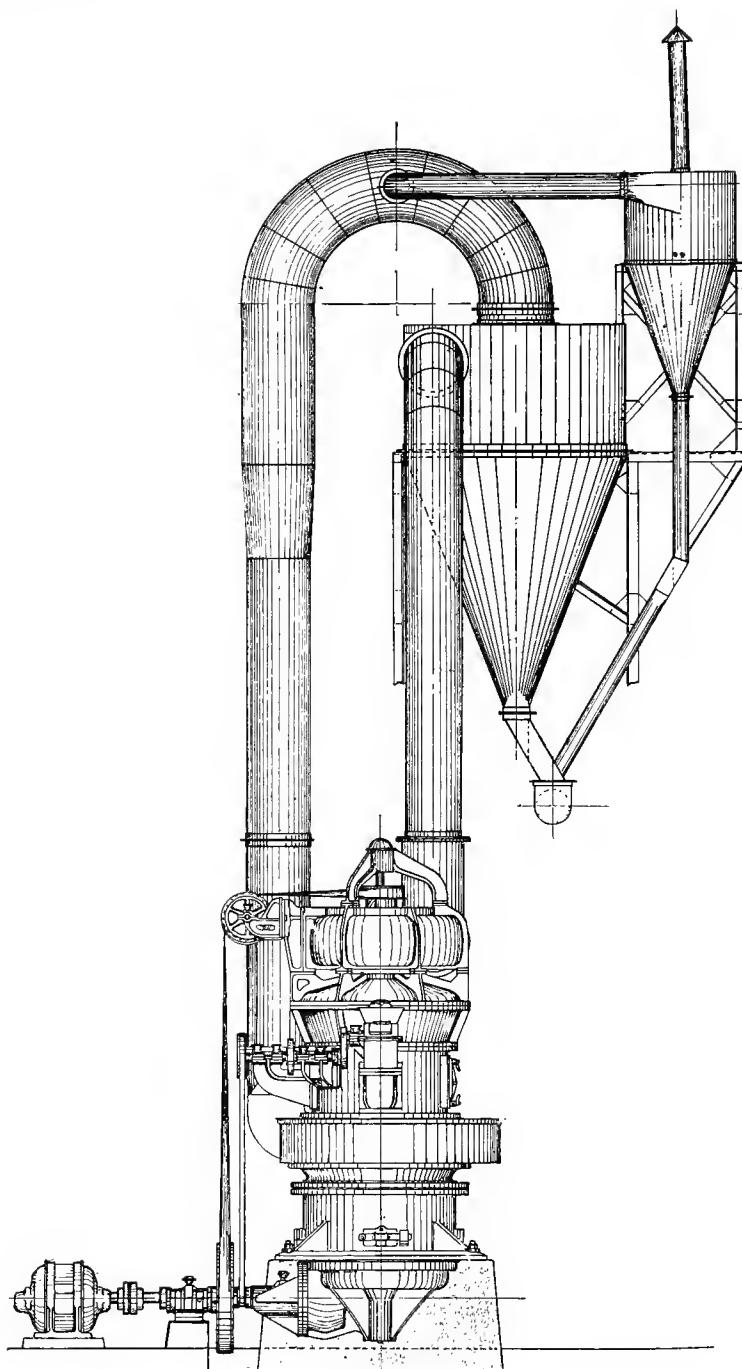


FIG. 6.—FULLER MILL ADOPTED FOR THE MILWAUKEE SUPER-POWER
STATION PLANT. (AIR SEPARATOR TYPE.)

CHAPTER IV.

TRANSPORTATION OF COAL DUST TO BURNERS.

In some instances the pulverised coal storage bins are dispensed with, the coal from the pulverising mills being delivered direct into a screen conveyor leading from the mill house to the building or buildings in which the coal dust is to be burnt. These cases are fast becoming the exception rather than the rule; newer methods of coal dust transportation by means of compressed air and low pressure air currents are now generally preferred.

Common practice for the transportation of the coal dust to the burners can be divided into three main groups with certain sub-divisions:—

- (1) By screw conveyors feeding into bins fitted at the furnaces or sub-stations :—
 - (a) thereafter fed through screw controllers to the burners;
 - (b) mixed at a sub-station by means of screw controllers and mixer fans with an air current and the mixed air and coal dust distributed to the furnaces through a system of supply piping;
 - (c) from the furnace bin the coal can be syphoned by the ejector action of compressed air.
- (2) By means of an "Air Pressure Transportation" system, in which the pulverised coal is delivered in known quantities into blowing tanks at the mill house. Compressed air is applied to the blowing tanks for the purpose of forcing any given quantity of coal through small supply pipes to the bins at the furnaces: *a*, *b* and *c* subsidiary systems given above for No. 1 method can equally apply to No. 2.
- (3) By means of the "Air Mixture" system in which the coal dust is mixed at the mill house with approximately half the quantity of air required for combustion of the coal dust. Supply is effected at a pressure of 10-12 ounces per sq. in. and at a speed of 90 ft. per second through the main supply pipes to the branch service at the furnaces. The main supply pipe makes a complete loop from and to the mill house, at which point the returning coal dust is extracted in a cyclone separator and re-delivered to the pulverised coal storage bin.
In certain cases where long lengths of main supply piping have to be used—say in a loop of 3,000 feet—probably one or two booster fans would be employed.
- (4) By means of the 'Fuller-Kinyon Pumping' system. This consists of a screw pump so placed as to receive the pulverised coal at the discharge from the mill. A small quantity of compressed air is introduced into the fuel 'as a lubricant' to prevent packing in the delivery pipes. In this way fuel can be delivered to any required number of bins, the rate of supply being controlled by ordinary valves. An outline arrangement of this pump and system is shown in Fig. 7.

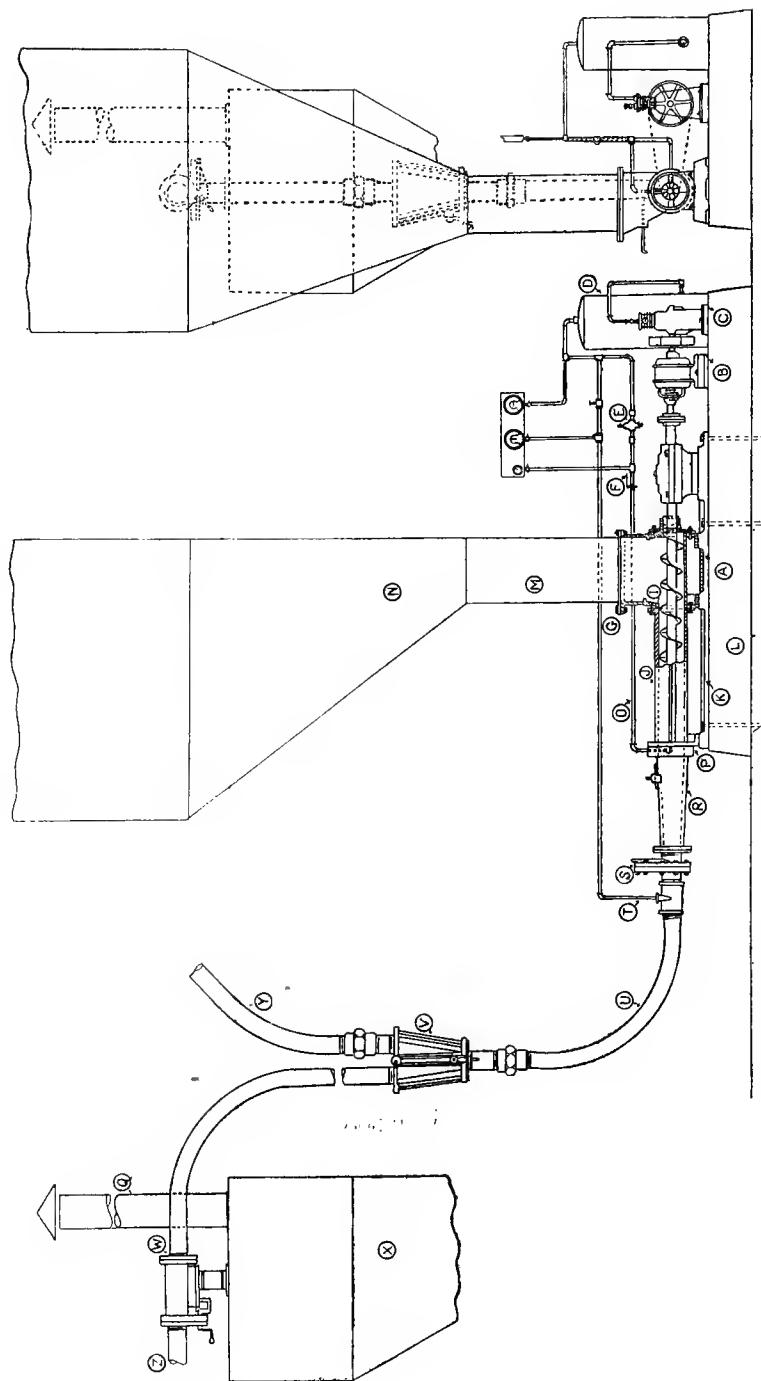


FIG. 7.—Arrangement of “Fuller Kinyon” Pumps (A) for delivery of pulverised coal from the mill or bin (N) to furnace or boiler bin (X) through supply pipe (V) and switch valve (V). showing small compressor (C) and power motor (B) for operating the unit.
(As a rule a separate compressed air supply is preferred.)

(5) For those who require only small quantities of pulverised coal and cannot therefore instal a complete milling plant, the supply of coal dust can be made by tank wagon or delivered in enclosed steel barrels or in special sacks. These methods are now in use for local requirements of customers, who can thus use coal dust for central heating systems in offices and warehouses and for general works requirements on a small scale.

No. 1 System, that of 'Screw Conveyors,' is still the one most in evidence in America for the reason that it is the oldest. It has its advantages, but they are few in comparison with the second and fourth methods described for 'long distance' transportation.

Screw conveyors have necessarily to be provided with substantial support frame work; they must as a rule be run overhead, along buildings, and where they cross railways or cartways must clear all traffic.

The raising and dropping of conveyor levels is not accomplished without some difficulty, especially when pulverised coal is being dealt with, for even on slightly inclined conveyors the powdered coal will at times flush right through the conveyor worm and pack up at the lower end. Any change in direction means a separate conveyor with attendant motor.

For relatively short runs, such as in a boiler house plant, or say one range of furnaces erected in close proximity to the mill house, it may often be quite satisfactory to use elevators and screw conveyors, and so dispense with the cost and upkeep of the air compressor plant.

No. 2 System.—'Air Pressure Transportation'—is one that has been adopted quite extensively of late. The interests in this patent, taken out in 1916 by Messrs. J. R. Magarvey, W. Salton and C. L. Heisler, are now controlled by the Quigley Furnace Specialities Co.

The writer has seen several installations where this system is in use, and the advantages pertaining thereto are considerable.

In this system what are called 'Blowing Tanks' are installed in the mill house. These are fed as required from pulverised coal bins. The tanks are arranged on weighing platforms, so that the weight of coal delivered into the tanks can be read off on the scale dials. The amount of coal dust transported to any bin can also be checked off by the same means.

The coal dust travels through ordinary 3 in. or 4 in. screwed piping to the bins at the furnaces. In view of stoppage due to moisture in the coal or condensation within the conveying pipes, a small companion pipe with tappings into the coal delivery pipe is provided. By this means compressed air can at any time be supplied through the companion pipe through the tappings or 'bleeders,' as the makers have termed them, and any stoppage of coal broken up and cleared.

It will readily be seen that this method of coal dust transportation can be effected through relatively small pipes and normal bends, which can be led overhead or underground with just the same convenience as water or gas pipes.

A very ingenious accessory to this system has been evolved by Mr. W. O. Renkin—engineer to the Quigley organisation—for the semi-automatic feeding of coal dust to any number of bins throughout the works.

In order to accomplish this, switch valves are placed at each turn out from the main supply pipe to a furnace bin. Each switch valve is fitted with a spring release and solenoid controlled catch. Each solenoid is operated by a push button at the mill house.

The mill attendant goes the round of the bins at the furnaces, notes the quantity required at each bin, sets the switch valve to 'supply,' and on completion of his round returns to his blowing tanks. From these he sends the quantity required to bin No. 1; and when the amount is registered on the scale dial he clears the coal from the supply pipe into No. 1 furnace bin, then he presses No. 1 solenoid release button, and despatches the quantity of coal dust to be sent to No. 2 bin. In this way the attendant can supply any desired quantities of coal direct from the mill house. This saving of labour and this degree of convenience cannot be claimed for screw conveyors.

No. 3 System.—'Air Mixture' is that employed by Mr. Holbeck in his patent system, which is handled by the Bonnot Company, of Canton, Ohio, and is also used to a certain extent in the 'Covert' system.

For compact plants, having a number of furnaces grouped together, and in cases where there are a number of small forge, rivet, bolt and nut heating furnaces, this system offers distinct advantages.

For heavy duty, where large quantities of coal dust are required throughout a works, the supply piping then becomes of considerable dimensions, and the velocity of mixed coal dust and air must be maintained at roughly 90 ft. per second, in order to eliminate the possibility of back-firing and to carry the coarser particles of coal dust in proper suspension.

In the original report it was mentioned that explosion doors and non-return valves had been recommended by users, and that although a latent danger of explosion may possibly exist, there are a large number of Holbeck installations in successful use in America, which would indicate that this danger is a remote one. Some serious accidents have recently occurred and a number of such air and coal dust conveyor systems have lately been removed.

With any system in which the coal dust is mixed in a high velocity fan with air, there is considerable wear and tear of ordinary steel fan blades and casings. To overcome this difficulty to a large extent mixing fans are of special construction. They are fitted with heavy cast iron casings and with blades constructed of special steel reinforced with manganese steel wearing surfaces.

No. 4 System.—The 'Fuller-Kinyon Pumping System' eliminates the use of elevators at the pulveriser mills. The transmission of the fuel throughout the works is effected through pipes in a manner somewhat similar to that of the 'Air Pressure System,' but with a reduction of power required. The introduction of a relatively small quantity of compressed air, sufficient to 'lubricate' the coal, produces an effect of a thick creamy body, which can be moved almost as a semi-liquid in one operation through ordinary pipe work to the receiving bins.

Coal delivered by 'Air Pressure' must be received in cyclone separators, which method introduces a certain loss of fuel at the vent stacks. The pumping system avoids the necessity for cyclone separators

and dust collectors; the fuel falls into the receptacle or bin direct from the delivery pipe, the surface of the semi-fluid body subsiding gradually as the air works out and escapes by way of the vent pipe.

The system appears to be less affected by climatic conditions than other systems in use, and after a shut-down over several days, the line being full of coal and the pipe frozen solid outside with snow and ice, the supply was recontinued without a hitch. As a precautionary measure an air supply pipe is run alongside the coal delivery pipe, so that coal lying in the latter after a period of shutting down can be aerated and discharged on restarting the supply pump. This system has been in successful operation at several works for many months and improvements in design of apparatus are still being made with a view to simplifying and perfecting this method of fuel transportation.

NOTES ON PULVERIZED COAL STORAGE AND SPONTANEOUS COMBUSTION.

Crushed Coal.—For all but the very large installations the coal when crushed to the size required for drying is stored in bins holding perhaps 20, 50, 100 or 200 tons and upwards, depending on the quantity of coal used per day. A two days' supply of crushed coal can be held in the Mill House bins and there is no trouble with spontaneous combustion at this rate of clearance.

Dried Coal.—It is sound practice not to store more than a 48 hours' supply of dried coal. Spontaneous combustion is not likely to occur in this time providing the coal as delivered from the drier is not overheated.

The terminal temperature of the coal as it leaves the drier should not be more than 200°F. but latitude in this direction is again governed by the nature of the coal and its ash.

Pulverised Coal at the Mill House.—A 24 hours' supply of pulverised coal should be the limit of storage.

Instances were cited by works engineers where through some cause or other pulverised coal in 30 to 30 tons bulk has been stored for 3 or 4 weeks without any sign of spontaneous combustion.

The only effect of spontaneous combustion in a pulverised coal bin is to produce a slight caking in the centre of the bulk. The actual fire is ultimately self-extinguished in the absence of sufficient oxygen to support combustion, and by the generation of CO₂ gas.

Pulverised Coal at the Furnace.—Bins holding 10 or 15 tons of pulverised coal have lain charged for 3 or 4 weeks in some cases without ignition, in others, fires have occasionally occurred overnight, producing 'central caking' in the coal bin; in the latter cases, the coal dust has either been discharged and taken away or it has been fed direct into the furnaces. The hot or caked coal has been carried through the feeder screws to the burners without damage to the apparatus or stoppage for cleaning out the bins.

It is considered good practice to store only sufficient coal at the furnace bin to last for one shift, 8 hours or so.

Explosion of Coal Dust.—At none of the works that were visited was it found that any special precautions had been taken against explosion of coal dust other than those dictated by common sense. Installations had been in use without any explosion having taken place for so many years that the danger of explosion had almost been forgotten.

In some of the older plants the pulverising mills, bins, girders, stairs, elevators, &c., were thickly covered with coal dust, which if dislodged over the open fires of driers erected in the same building would undoubtedly become ignited. An unnecessary risk of fire, even if not of actual explosion, is being courted in several plants.

The existence of such conditions in the mill house for years without mishap should reassure those who are excessively fearful of coal-dust explosions.

At the new plants greater attention has been given to keeping the mills and mill house clean—in fact the new types of mills and the care now given to design of plant makes for a dust-tight equipment.

Bins, for the supply of coal dust to open hearth furnaces, covered with coal dust and erected close to the ends of adjoining furnaces, have been in existence for six or seven years. So close were these bins to the furnaces that, owing to heat radiated through the open joints of the furnace end walls, the bins were quite hot to the touch, and yet at these works no fire, flare or explosion had ever taken place.

With due exercise of common sense there is therefore no danger of explosion either in the mill house, throughout the coal-dust transport system, or at the furnaces.

In one works it was reported that one or two flares had occurred. These accidents had been caused by men painting the roof and dislodging coal dust from the trusses and loose planks that had lain for months over the furnaces.

The dislodged coal dust had mingled in its fall with the air inside the building, had formed an explosive mixture which had ignited at the open door of the furnace. Even such events as these were not looked upon with any degree of anxiety.

The following precautions should be observed in storing powdered coal:—

1. Limit the height of the coal pile to 10 or 12 ft.
2. Isolate the coal from all sources of heat such as steam pipes, flues, reflecting surfaces and direct sunlight.

Mr. C. P. Beistle, chemist of Bureau of Explosives, U.S.A., has also contributed to this investigation, and in an article of his in the Railway Age Gazette, October 12th, 1917, he says:—

“The pulverised coal should be stored in metal bins or receptacles sufficiently tight to prevent circulation of air or the entrance of moisture. The amount of pulverised coal kept in storage should be as small as is practical, considering the daily consumption: the reserve of fuel should be stored in the lump condition and not as pulverised coal. In case pulverised coal ignites spontaneously, or from any other cause, it burns slowly with smouldering combustion, and if kept in tight metal bins is not liable to cause much loss.”

" In common with other combustible dusts, such as flour, elevator dust, &c., under certain conditions coal dust or pulverised coal is capable of producing violent explosions. This explosive action can take place only when the dust is suspended in the air, and then it requires the contact of a spark or flame for ignition."

" Storage bins, driers, pulverisers and conveyors should be tight to prevent the escape of the pulverised coal into the atmosphere. Coal dust should not be allowed to accumulate on exposed surfaces inside of buildings or in other places where by any means it may be thrown into the air to form a dust cloud."

" No lights other than incandescent electric lights, provided with heavy guards, should be permitted in places where pulverised coal is being prepared, handled or stored. Fires, matches, lanterns or torches should not be permitted in or around pulverising mills or storage bins."

" The inflammability of pulverised coal depends on the proportion of volatile matter in the coal and, therefore, bituminous coal is more dangerous in this respect than anthracite coal, and lignites are more dangerous than bituminous coal. While pulverised anthracite coal is not liable to spontaneous ignition and is less liable to produce dust explosions than other coal, the coal commonly pulverised for use as fuel is bituminous coal or lignite, as pulverised anthracite coal has not yet been successfully applied as a fuel, except when mixed with softer coal."*

In a report upon a recent invention by Mr. Hudson Maxim, this question of explosibility of coal dust is very thoroughly examined.†

When considering the particular use of which coal in pulverised form was required several objections were raised thereto—namely:—

1. Danger from explosive mixtures of coal dust and air;
2. Settling down and caking in the supply tanks or bunkers;
3. Danger from spontaneous combustion in the tanks or bunkers.

These objections are clearly dealt with in the report referred to by the following remarks:—

" As already pointed out, no coal dust can escape into the atmosphere by the method intended to be employed. It has been found also that caking or settling down in the bunkers offers no impediment worth consideration to the Quigley method of conveying pulverised coal, for the packed coal is easily fluffed up by compressed air and reduced to a condition for conveyance without any difficulty."

" Lastly, there will be and can be absolutely no danger whatever from spontaneous combustion. It is impossible for coal to burn without air, and it requires twelve pounds of air to burn one pound of coal. In the bunker cylinders the volume of pulverised coal and air will be about equal to each other, that is to say, each cubic foot of pulverised coal contains voids filled with air about equal to the actual bulk of the coal itself."

* Straight anthracite has now been successfully used.

† It can now be stated that this invention related to a powdered coal fired torpedo-proof cargo carrying steamship.

"A cubic foot of air weighs one-twelfth of a pound at atmospheric pressure, and one-half of a cubic foot, therefore, weighs one-twenty-fourth of a pound. The weight of a cubic foot of pulverised coal is about forty pounds, so that we have in a tank only one-twenty-fourth of a pound of air to burn a cubic foot of coal, instead of twelve pounds of air per pound of coal, or four hundred and eighty pounds of air, the quantity needed to burn forty pounds of coal. Twenty-four times four hundred and eighty is 11,520, so that there is not one eleven-thousandth part of the air present necessary to burn the coal."

"That such a limited quantity of air would be able to support the combustion of so much coal is utterly absurd."

"Furthermore, one of the most efficient fluids for extinguishing combustion is carbon dioxide, and immediately, should there be any combustion of coal in a closed cylinder, carbon dioxide would be generated and the gases of the burning coal would therefore very quickly extinguish the fire."

"The impression that pulverised coal is liable to spontaneous combustion arose from the fact that if pulverised coal be exposed to the air in such wise as to admit of free contact and circulation of the air, oxidation of the pulverised coal will take place and heat will be generated, and if the heat is not permitted to escape freely it will very likely rise to the temperature of ignition, and the coal will fire and be consumed, for the products of combustion will be permitted to escape as fast as formed and fresh air admitted to the fire."

"But such conditions do not and cannot obtain in a closed steel cylinder, consequently there is absolutely no danger from spontaneous combustion of coal in closed steel cylinders."

CHAPTER V.

FEEDERS, MIXERS AND BURNERS.

It can be said that nearly all the faults and failures which applied to early attempts to burn pulverised coal in a relatively confined combustion space, but not applying to open hearth furnaces and the like, were due to the use of high velocities for the combustion gases consequent upon a high-pressure air supply.

The present tendency is to use low-pressure air supply for mixing with and introducing the coal dust into the combustion chamber or furnace, thus allowing the particles of ash to settle out before reaching the work to be heated or the boiler tubes and surfaces.

Burners are, therefore, not as a rule of a complicated nature, and more often than not the coal dust is simply allowed to fall by gravity from the feed screw into the single pipe which carries the air for combustion of the fuel. The pressures used vary from 2 up to 6 or 8 ozs. per square inch, but the lower the pressure the better.

FIG. 8.—INSTALLATION OF PRUDEN BURNERS AND MIXERS ON REVERBERATOR FURNACE. RIVER SMELTING & REFINING CO., FLORENCE, Colo.



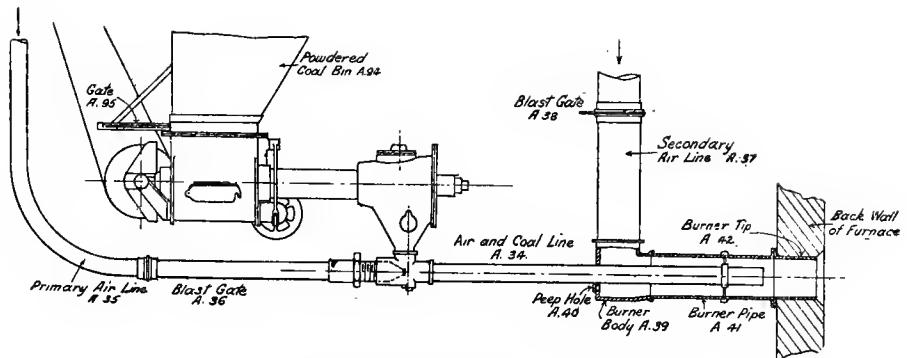


FIG. 9.—QUIGLEY NEW PRESSURE BURNER.

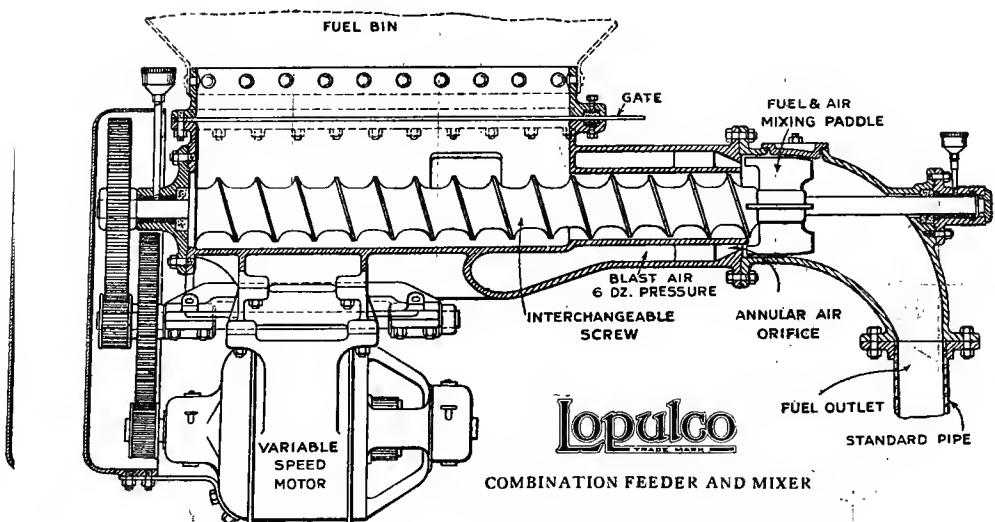


FIG. 10.—LOCOMOTIVE PULVERIZED FUEL COMPANY.

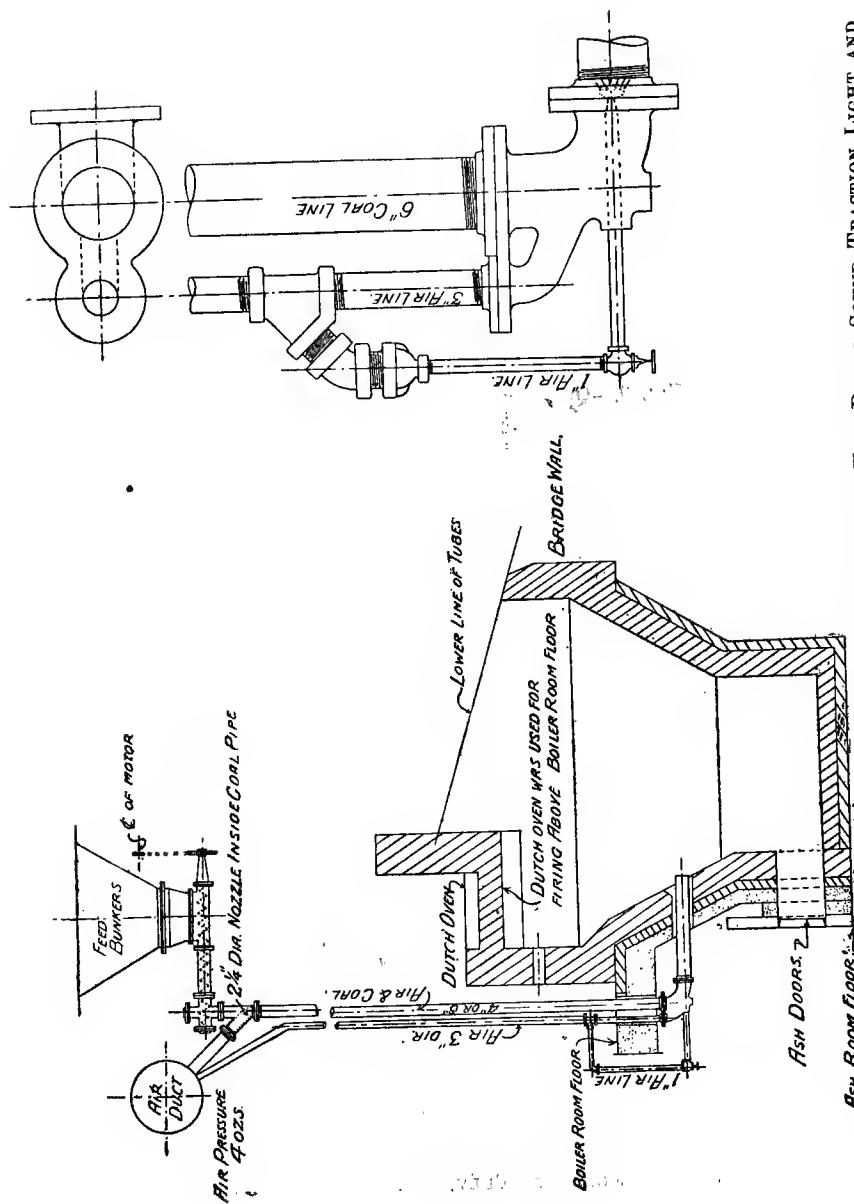


FIG. 11.—ARRANGEMENT OF "SANTMYER" BURNER AS IN USE AT THE PUGET SOUND TRACTION LIGHT AND POWER COMPANY'S GENERATING STATION, SEATTLE, WASH.

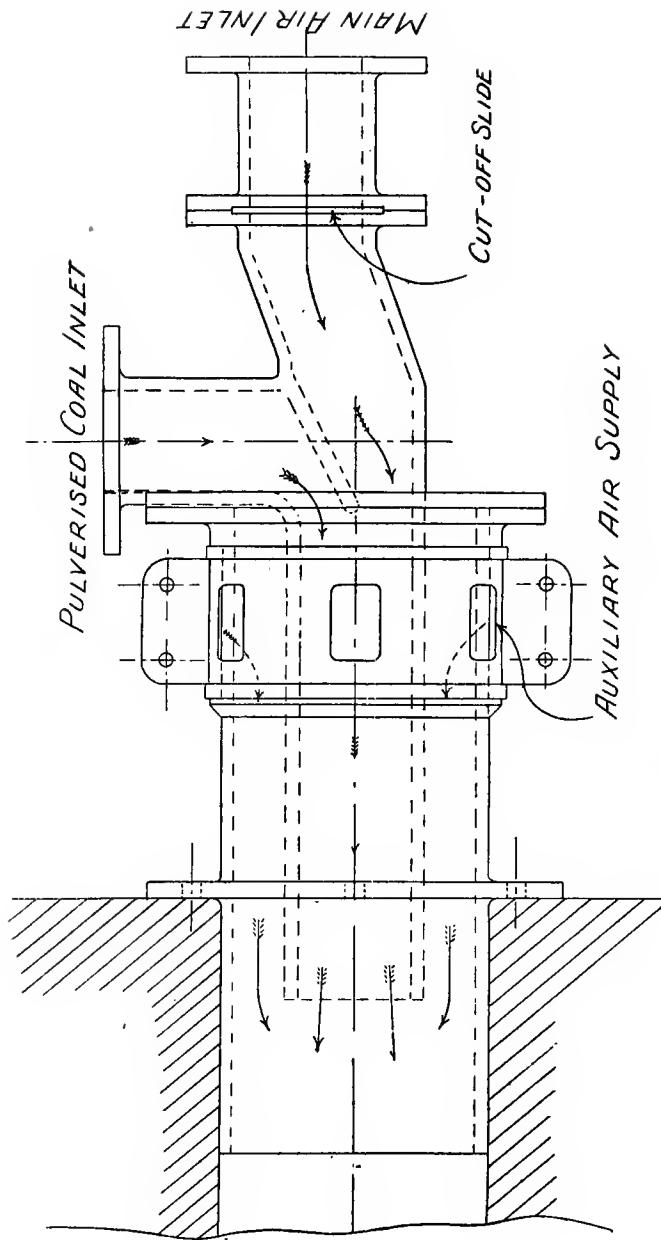


FIG. 12.—ARRANGEMENT OF FULLER BURNER.

Missing Page

One form of "Quigley" burner has a double air supply, provided from the one source. The primary air has an ejector action upon the supply of powdered coal. The initial mixture of coal dust and air is then introduced into the main air supply just prior to its entry into the furnace. The pressure of the air supply at the point of entry of the fuel is about 2 to 3 ozs.

The "Fuller" burner usually consists of a single air pipe or burner tube into which the coal dust falls by gravity from the screw feeder. The pressure of the air supply is generally 2 ozs. per square inch.

The "Bergman" burner is fitted with an internal cone, fitted concentrically within the air supply pipe, and the coal dust is fed in by gravity in such a manner that it forms a complete film or coating to the air jet. The purpose of this is to introduce the air into the furnace in the centre of a covering of fuel. It is contended that when coal dust is fed into the centre of the air jet, the latter expands away from the pulverised fuel, and an imperfect mixing of the air and fuel in the furnace results.

The Locomotive Pulverised Fuel Co.'s mixer is combined with the screw feeder. The burner consists only of the pipe through which the mixed coal and air is conducted to the furnace.

In practice air is supplied at 6 to 8 ozs. pressure, and enters the jacket surrounding the delivery end of the screw feed. At this point the mixed coal and air is given a whirling motion by means of the paddle blades, which thus assists the intimate mixing of the fuel and air for combustion. From this combination feeder-mixer a number of burner tubes can be supplied.

The Heyl and Patterson Co. ("Covert" system) have several types of burners or mixers. One of these is of special interest. The coal dust falls into this burner in the usual manner by gravity, and on to diaphragm shelves projecting one below the other, and fitted horizontally across the air inlet pipe or burner tube. Air is supplied at 2 or 3 ozs. pressure, and picks up the coal dust on passing between the shelves.

Other types of burners will be illustrated and described in the writer's paper for the Iron and Steel Institute, but the information given above will indicate the general lines on which American practice is based.

All the above feeders, with the one exception of the "Quigley" type, operate with variable speed motors for the control of the supply of coal dust to the burners. The Quigley feeder is fitted with adjustable jaws through which the coal dust is passed to the burner. The feed screw can, therefore, rotate at a constant speed.

The "Pruden" Carburiser or Mixer supplied by the Powdered Coal Equipment and Engineering Company effects perhaps the most perfect mixture of coal dust with air. The powdered coal as it is withdrawn by screw feeder from the bunker is mixed with a primary supply of air and this mixture is then conveyed to a second chamber in which the balance of air required for combustion is introduced into the primary mixture. As applied to reverberatory furnaces this apparatus is shown in the illustration.

For open hearth work compressed air at 60 to 80 lbs. per square inch is often used as a medium for ejecting the fuel from the supply bin and for directing a long flame on to any particular portion of the bath, pre-heated low-pressure secondary air being introduced at the burner nozzle.

The 'Santmyer' burner is shown in Fig. 11. The operation of this burner can be clearly seen by reference to the illustration. It has been introduced in this report because Mr. Santmyer was the first engineer to burn pulverised fuel successfully on the West Coast; his burners being fitted to the boiler furnaces at the plant of the company mentioned and have been in continuous operation since 1917.

CHAPTER VI.

APPLICATIONS; OPINIONS OF USERS; WORKING RESULTS, ETC.

See table facing page 22 for information received in answer to questionnaire sheets sent out recently.

(1) METALLURGICAL AND SIMILAR PROCESSES.

The Cement and Copper Smelting industries were not specially studied for the purpose of this Report. The use of powdered fuel in connection with the former is too well known to need description here. Although copper smelting is in Great Britain at present a comparatively small industry, the following description of present-day American practice may be of interest:—

It can be accepted that the use of pulverised coal in copper smelting furnaces has become general practice in America. Originally built for oil or hand coal firing, most of the large copper ore reducing furnaces have now been converted during very recent years to firing by powdered fuel.

It was in January, 1915, that the American Institute of Mining Engineers published a paper on this subject by Mr. David H. Browne. In this paper the author reviews previous attempts to apply pulverised coal to copper smelting furnaces, and then records fully the successful methods introduced by him in connection with the reverberatory furnaces at the works of the Canadian Copper Co., Copper Cliffe, Ont. At these works smelting had been carried out for 20 years in blast furnaces.

In 1906 and 1908 two previous investigations and actual applications of powdered coal had been made, one by Mr. Sorensen at the Highland Boy Mines at Steptoe Valley, and one by Mr. Charles Shelby on furnaces at Cananea.

Fuel ratios were then about 4.1 of copper to the ton of coal, and it will be seen from later figures mentioned in this report, that a 7.24 ratio has been obtained for continuous work. Furnaces at the Canadian Copper Co.'s works were put into operation during the winter, 1911-12, results for the first three months being:—

—	Total Charge.	Charge per Day.	Ratio.
January	12,897 tons.	416 tons.	5·0 tons copper per ton fuel.
February	12,149 "	434 "	5·65 " "
March	14,195 "	458 "	6·77 " "

Latest practice at these works, a practice that has since been adopted by other companies, is to brick up all side charging doors and to provide a shallow channel along each side and over the top of the furnace, with charging pipes through which the charge is introduced into the furnace. The copper ores falling through these charging pipes adheres to the side walls of the furnace, thus protecting the brickwork and greatly prolonging the life of this part of the furnace.

The furnace is some 112 ft. long by 20 ft. wide inside. The coal then used was a good quality of slack, showing—

Volatile matter	...	...	...	...	Approx.	34 per cent.
Fixed carbon	...	...	...	...	„	55 „
Ash	...	...	...	...	„	9 „
Sulphur	...	...	...	...	„	1 „
B.Th.U.	...	...	...	...	...	13,500

In the pulverised form 95 per cent. passes the 100 mesh, and 80 per cent. through a 200 mesh. The furnace is fitted with five burners, each delivering about 13.5 tons of coal per day, or 19 lbs. per minute. The total coal used per day is about 7 tons.

Mr. Browne says that the ash from the coal causes very little trouble, a small percentage settling on the slag, a small amount in the flue, and a few hundred pounds may stick around the throat of the furnace.

In the same journal of the American Institute of Mining Engineers, Mr. Louis V. Bender writes on the work carried out at the Washoe Reduction Works of the Anaconda Copper Co.

Following upon the success made by Mr. Browne in Ontario, one of the Anaconda furnaces was adapted for pulverised coal firing in 1914.

Two results tables are reproduced from Mr. Bender's paper; these show the analyses of coals used, the fuel ratios and a comparison for coal consumption with ordinary hand grate practice.

—	Mois-ture.	V.C.M.	F.C.	Ash.	B.Th.U. Dry.	Length. of Test Days.	Tons Smelted per Day.	Fuel Ratio.
Lockray ...	8·0%	29·3	41·8	20·9	10,350	12	409·4	5·38
Bear Creek ...	9·0%	35·5	43·4	12·7	11,500	18	406·7	5·57
Diamond Ville ...	5·6%	41·4	44·9	8·1	12,960	30	475·8	7·24

On the new Anaconda furnaces it was then expected to reach a fuel ratio of 7·5 for straight through work. The advantage of using fuel in powdered form as against hand-firing is shown by the following figures:—

—	Tons Smelted per Furnace per day.	Total Tons Smelted.	Tons Coal.	Fuel Ratio.
Furnace grate fired ...	250·96	7,260·31	1,870·94	3·88 tons of charge
„ dust „ ...	475·75	14,272·52	1,984·77	7·08 „ „

NOTE.—Fuel ratio for dust firing includes coal used in drier.

This shows a considerably increased output from the coal dust fired furnace.

In the discussion following these papers much useful information is given, and as an instance of the large size of some of the American reverberatory smelting furnaces, a reference is made to one of 144 ft. in length with an inside width of 25 ft. From this furnace, using pulverised coal, a daily output of 750 tons is obtained. It was reported in 1915 that furnaces of 175 ft. in length would be put down at Anaconda under the £1,250,000 (\$6,000,000) extension scheme of the Anaconda Copper Co. In this discussion Professor J. W. Richards made the following remarks:—

"Comparing coal dust firing with coal grate firing, the difference is, that in burning coal on a grate not more than two-thirds or three-quarters of the heat generated by the coal by combustion goes into the furnace. There is a loss of 25 to 33 per cent. of the calorific power of the coal by radiation from the sides. By coal dust firing this is obviated. That is the essential basis of the greater efficiency of the coal dust firing."

Further on Professor Richards says with regard to furnace efficiencies:—

"Roughly it amounts to this: if you lose one-quarter of the calorific value of the coal in a fire place, you have only three-quarters to be utilised in the furnace.

"The heat loss at the flue end is a constant, and would be the same for both." (Hand firing or coal dust firing.) .

"Let us say the charge is heaped the same way in both furnaces, the amount of heat then absorbed would be the same in both, and in one case you would have some ratio of 75 per cent., and in the other some ratio of 100 per cent.

"If in grate firing you have 15 per cent., you have 15 per cent. of 75 per cent., or about 11 per cent. In the other case you get 15 per cent. of 100 per cent., or 15 per cent. net."

It was further stated at this meeting that on the introduction of coal dust firing at Anaconda, the cost per ton for smelting was reduced by 2s. 1d. (50 cents) per ton, which is probably represented by the economy in fuel.

Of the 1,396,600 tons of copper computed to have been the world's products for 1916, some 860,647 tons were produced in America.

If one considers the amount of coal required to smelt, say 1 million tons of copper ore, on the basis of the figures given by Mr. Bender, the comparison between grate firing and coal dust firing would be:—

	<i>Coal tons.</i>
Grate fired reverberatory furnaces	257,732
Coal dust fired " " " "	141,242

Over 100,000 tons of coal saved per million tons of charge smelted.

BLAST FURNACES.

The following information has been extracted from the 21st November, 1919, number of "Engineering," and will show the progress being made and the results already obtained in applying pulverised coal as a blast furnace fuel:—

"Experiments at the Tennessee Copper Company's Smelter.— Experiments at the smelter of the Tennessee Copper Company were decided upon early in 1918, one of their standard blast furnaces, 22 ft. 6 in. long by 60 in. wide, being used. Ten tuyeres on one side of the furnace were equipped for the use of pulverised fuel, and the first test run of importance started on 22nd April and was continued until 4th May, during which period the percentage of coal to the charge was 3·8 as against 5·7 of coke used on the other furnaces during the same period, when operating with a similar charge. The second test run started 9th May, and continued until 24th May, when the percentage of coal used was 3·6, a very small amount of coke being used intermittently.

"A third test run was then made, feeding a little coke on the side of the furnace where no coal was fed previously, as it had been found there was a tendency for crusts to form on that side of the furnace. It was then decided to apply the coal at 10 tuyeres on each side, but experimental work was postponed, owing to the possibility of some unconsumed carbon in the furnace gases causing discolourisation and affecting the quality of the acid, which is an important product of the company, particularly during the war, when a portion was used in the manufacture of high explosives. The war requirements in this connection no longer existing, the company returned to the experimental work in January, and are continuing, with various modifications, the methods of applying the coal.

"Experiments at the International Nickel Company's Smelter at Copper Cliff, Ontario.— Following the work of Garred, already described, the International Nickel Company decided, in June, 1918, to carry out experiments in the blast-furnace department of their smelter at Copper Cliff, Ontario. It was decided to utilise one of their standard blast furnaces, which are 25 ft. 6 in. long by 50 in. wide. The furnace bottom is lined with magnesite brick to within 14 in. of the centre of the tuyeres; the two lower rows of jackets are of cast-iron with water-cooled pipes, and the two upper rows of jackets are of the standard water-cooled steel type. The furnace has 48 6-in. tuyeres, 24 on a side, spaced about 12 in. centres. These are connected to a main bustle pipe with 6-in. galvanised branch pipes fitted with canvas sleeves. The bustle pipe is supplied, by an offset, from the main delivery pipe which feeds seven other furnaces, the normal pressure of air carried at the tuyeres being 23 oz. to 24 oz.

"The furnace charge consists mainly of a refractory copper-nickel sulphide ore, a large proportion of which is delivered from the company's roasting plant.

"The furnace, under normal conditions of smelting, treats about 500 tons of charge a day, utilising 60 tons of coke; the average consumption for six months being 12·5 per cent. of the charge."

LIQUID IRON AND STEEL DIRECT FROM THE ORE.

The pulverisation of coal and its application as a fuel in this form renders possible the generation of maximum temperatures in contact with metalliferous ores.

This principle has suggested from time to time the reduction of iron ore to liquid metal without recourse to blast furnace practice.

In November of this year, 1920, reference is made in the technical journals to such a process worked out by the French engineer Mons. Lucien Basset.

This process has been acquired in France by the "Société Française des Acieries Basset," and is as follows:—

Inclined rotating furnaces fired by means of pulverised coal are employed, the air for combustion being preheated to 1,000° C. Gases leave the furnace at a temperature of 300° C., and as they contain some 44 per cent. CO can be used for further heating purposes.

It is said that 2,500 tons of liquid iron have already been obtained in France at the Longwy and Caen works by this process.

It remains to be seen whether this fresh attempt to produce iron and steel direct from the ore can be successfully established.

LIME BURNING AND FERTILISER MATERIALS.

Much has already been done with regard to applying pulverised coal as a fuel for firing rotary kilns for calcining and burning lime and fertiliser materials. This application is similar to cement works practice.

What is claimed to be the largest lime plant in the world has been recently built at Muscle Shoals, U.S.A., and the kilns are entirely pulverised coal fired. There are eight kilns each 125 ft. long and 8 ft. diameter, provided with 50 ft. coolers. Each kiln has a capacity of 100 tons of lime per day.

The operating engineer, Mr. G. E. Cox, states that: "The ratio of coal to lime burned was about 2·8 lbs. of lime to 1 lb. of coal. The quality of the coal, however, was inferior. With a good grade of coal it is easily possible to burn 3 lbs. of lime to 1 lb. of coal."

In view of the pressing need of obtaining adequate quantities of burnt lime and fertiliser materials, this method of using waste or low-grade coal for firing kilns of this description should be seriously considered by manufacturers.

Successful installations of pulverised coal equipment seen in operation covered the following applications:—

- Open hearth steel smelting furnaces,
- Continuous billet heating furnaces,
- Heavy forge furnaces,
- Light forge furnaces,
- Bushelling and pipe welding furnaces,
- Puddling furnaces,
- Soaking pits,
- Annealing furnaces,
- Sheet and pair furnaces,
- Rivet heating furnaces,
- Galvanising and tinning kettles,

Domestic and office buildings central heating,
 Stationary boiler plants,
 Railway locomotives,
 and latterly,
 The experimental boiler equipment fitted on U.S. Scout Patrol Ship
 "Gem."

Systems now in use in America for the purposes mentioned above are recorded on page 52 and a list of the installations in existence, and of those actually visited will be found on pages 52 and 53.

In repeating the opinions of users and owners, it has been thought better to omit the actual names of those who have been good enough to express their views.

STEEL INDUSTRY.

It will be necessary to separate out and to group together some of the applications inspected in steel works.

OPEN HEARTH STEEL MELTING FURNACES.

Advantages Claimed.

Pulverised coal can be applied with assured success, showing in some cases economy in fuel over producer gas firing with, however, no additional life of brickwork, but slightly the reverse.

Range of Fuels Available.

A good grade is desirable, a suitable analysis being as follows:—

Volatile matter	...	...	Not under	36·00	per cent.
Fixed carbon	...	...	" "	52·00	"
Moisture	...	...	Not over	1·25	"
Ash	...	...	" "	6·00	"
Sulphur	...	...	" "	1·00	"

Disposal of Ash and Slag.

Approximately 50 per cent. of the ash settles on the bath of steel and is tapped off in the usual manner. 30 per cent. to 40 per cent. should be deposited in the slag pockets provided for this purpose, and 10 per cent. to 20 per cent. will accumulate in the chequers, principally on the first few rows of brickwork.

Opinions of Users.

(1) "Would not recommend powdered coal in preference to producer gas, or coke oven gas of 500 B.Th.U. For producer gas furnaces 6 million B.Th.U. are used per ton of steel, for powdered coal furnaces from 6½ to 7 million."

(2) "The tar and by-products make firing by means of producer or coke oven gas more profitable."

(3) "Pulverised coal would be satisfactory for intermittent work, but for continuous output no time can be spared for cleaning out ash deposit in chequers and flues, if powdered coal were used."

(4) "For small plants where time permits the cleaning out work to be done, would recommend pulverised coal."

(5) "In relatively small plants results have shown a consumption of coal in powdered form of 540 lbs. per ton of steel as against 650 lbs. in gas producers."

Note.—This gentleman was comparing his steel melting plant of some 20 or 30 sixty to two hundred ton furnaces with the "relatively small" plants.

(6) "We have not used powdered coal for a number of years in any department of our plants. We had an installation and at one time ran six Open Hearth furnaces on powdered coal. Owing to the size, character and construction of our furnaces and to the fact that, in my judgment, we did not pulverise our coal as finely as ought to have done, we found the method entirely too expensive in the way of furnace maintenance and reduced output to warrant its continuation. We also found some difficulty with the quality of steel made. Our furnaces were not susceptible to such change as would have made that fuel successful, if it is capable of successful Open Hearth use. We used the process for about two years from the time we first made our experimental heat until we abandoned it. I have some doubt as to whether powdered coal can be efficiently and economically used in Open Hearth practice, although I am still inclined to the opinion that it can be if furnaces are especially built and designed from the beginning for that fuel and if a dependable source of fuel, low in sulphur and low in ash, can be had."

(7) "Prefer tar to powdered coal; better heat and no trouble with ash. Powdered coal more economical than producer gas, but would prefer tar to anything."

(8) "Two 45 ton furnaces on powdered coal, two on tar heats with the former fuel take 8 to 10 hours, but 11 to 12 hours after cleaning out the chequers. Average coal consumption 422 lbs. per ton of steel, consumption of tar 45 to 50 gallons (American) per ton. Chequers with powdered coal firing naturally wear out more quickly than when tar or gas is used, the practice being to clean out one end after 40 to 50 heats, and the opposite end after the subsequent heat, the time taken to complete each operation being 2 hours."

(9) "Coal used to run under 1 per cent. sulphur, but now it takes more lime to counteract the increased percentage of sulphur. No other trouble is experienced with the use of pulverised coal. The installation has been in continuous use for six years."

The average sulphur and ash content of the coals then being burned showed: Ash about 8 per cent., sulphur about 2·25 per cent.

(10) "For open-hearth furnaces using powdered coal would advocate the provision of three sets of chequers instead of the usual two sets. Average life of chequers before rebuilding becomes necessary, 150 heats, much of the brickwork being, of course, used again."

(11) "No severe cutting away of the furnace lining experienced, and can be put in a new back wall in 2 hours after charging a heat."

(12) "Discarded producer gas in favour of pulverised coal on account of lower cost of running the plant and greater output obtained thereby. This has been definitely confirmed in practice, the monthly output with producer gas being from 10,000 to 11,000 tons and with the powdered coal furnaces 16,000 tons."

(13) "With powdered coal there is no necessity to burn out the flues as is the case with producer gas; this operation had to be carried out every three weeks, whereas it is now possible to run the coal-fired furnaces day in and day out for 150 heats."

(14) "Difficulty was at first experienced with the choking-up of the chequers, the fineness of the coal then being 95 through a 100 mesh. Since we have ground to 95 through a 200 mesh these difficulties have practically disappeared."

(15) "Four open-hearth furnaces, each of 28 tons capacity, have been running on powdered coal for some years. There is considerable economy over producer gas which was previously used."

(16) "On the last year's figures, coal used in powdered form was at the rate of 500 lbs. per ton of steel; previously, with producer gas, the consumption was about 800 lbs."

Note.—This is an instance, presumably, where producer-gas firing does not show economical results for the relatively small steel plants, referred to above, on another occasion.

(17) "Naturally try to obtain coal as low in ash and sulphur as possible, but recently have had to use any coal available, but increased sulphur content does not mean much, whilst the increased quantity of ash has not prevented the successful working of the furnaces. Coals having from 0·55 to 3·67 per cent. sulphur, and from 1·39 to 6·58 per cent. ash, have been used."

(18) "Regenerators must have large openings in the chequer work, with which arrangement relatively high ash coals can be used. If the chequers cannot be re-designed it will be essential to pick a coal low in ash."

(19) "The chequers at this plant last some 300 heats, with occasional clearing out of the first few courses."

(20) "With regard to the life of brick linings, it is found that with oil firing the life is longest, for producer gas and powdered coal firing the life in each case is about equal."

(21) "Capacity of open-hearth furnaces, 60 tons. A cold charge is brought out in 12 to 13 hours, using 500 lbs. of powdered coal per gross ton of ingots cast. Have used coals with 6 to 20 per cent. ash, but recommend keeping below 6 per cent. ash and sulphur under 1 per cent. Hot charges are run in 7 hours."

(22) "Chequers last 250 heats and are then entirely removed, laying the furnace off for two weeks. For this reason would prefer producer gas, with which it is possible to renew the chequers and roof in one week, so that 12 weeks' working are lost when powdered coal is used."

(23) "It is anticipated, however, that from the results obtained with the new furnace specially designed for powdered coal firing, the life of chequer work will be at least doubled."

(24) "Have 14—16-ton open-hearth furnaces which were originally designed for natural gas. Producer gas was not considered because the cost of the pulverised coal plant was 60 per cent. less than that for producer gas."

(25) "Have found that the average life of chequers for various fuels approximates:—

- " Natural gas, 1,000 heats.
- " Producer gas, 350 to 500 heats.
- " Oil, 350 to 500 heats.
- " Powdered coal, 225 to 250 heats."

The first successful steel-melting plant in Canada has been started up this year, 1920, at the Manitoba Rolling Mills. The capacity of the furnaces is 60-90 tons of steel ingots per day.

HEAT-TREATMENT STEEL FURNACES.

Advantages claimed.

Pulverised coal offers considerable economies over all other fuels. The metal if brought up to welding temperature, as in skelping, busheling, and tube-welding furnaces, is softer to work and there is an appreciable decrease in oxidation. Soaking pits and forging furnaces, if fired with powdered coal, produce a more easily-worked billet, the heat soaking through the metal more uniformly than in furnaces fired with oil or gas. Here, again, the reduction of oxidation is appreciable.

Range of Fuels available.

In furnaces for the heat treatment of steel for rolling or forging, the best results will be obtained by using the best grade of coal obtainable. Fuels with ash content higher than 15 per cent. should be avoided if possible. A fuel containing less than 10 per cent. ash is preferable for this work in order to obviate the difficulties attendant upon the covering of the work with a heavy coating of slag. The volatile materials in the coal should be from 30 per cent. upwards.

SOAKING PITS.

"Soaking pits are run up to a temperature of about 2,000° F., and the amount of coal used is 190 lbs. per ton of steel (3,300 lbs. ingots)."

CONTINUOUS BILLET-HEATING FURNACES.

Disposal of Ash and Slag.

About 40 per cent. of the ash will be thrown in the combustion chamber. 20 per cent. as liquid slag in the final heating or discharge end

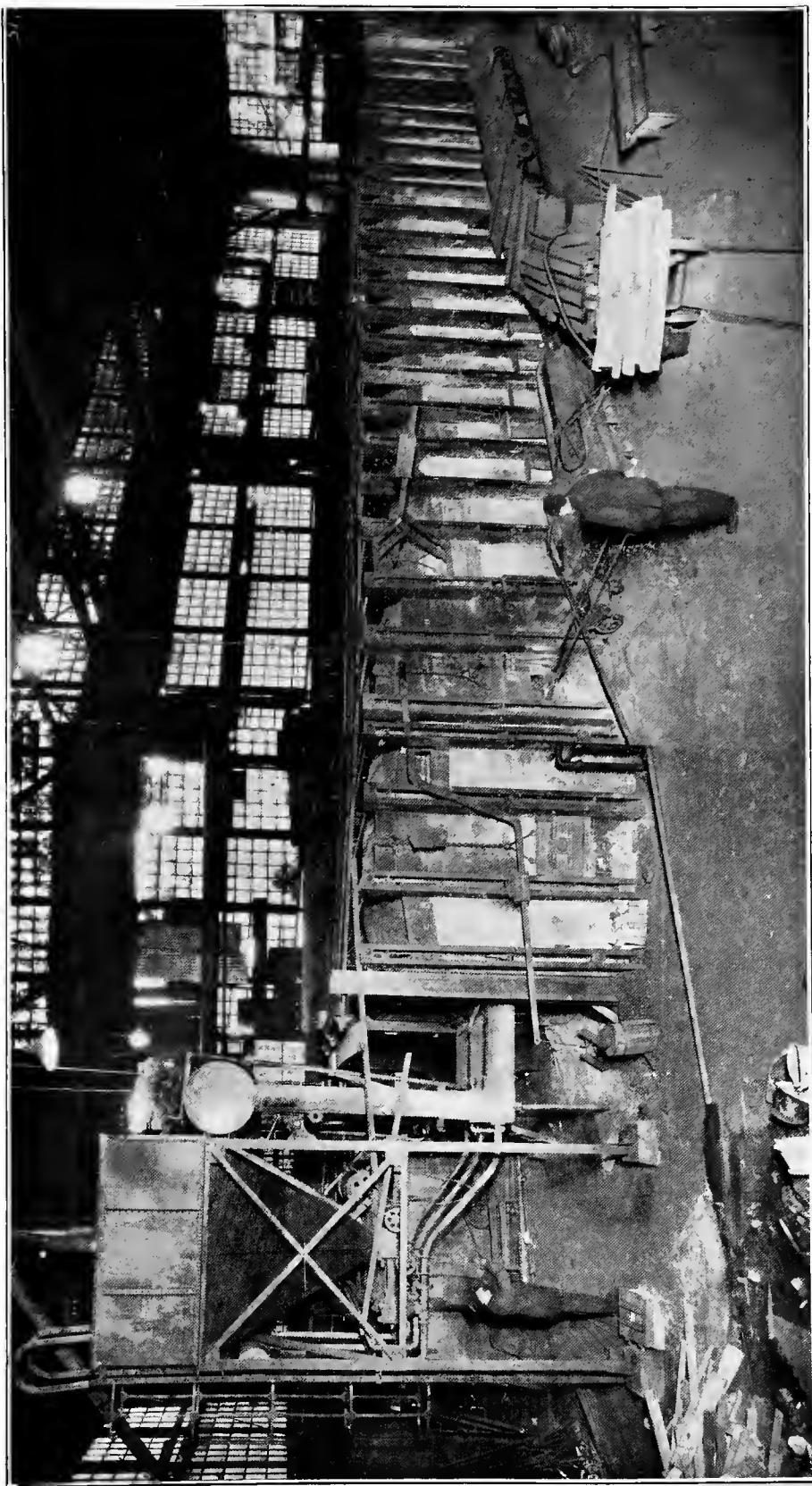


FIG. 14.—CONTINUOUS BULLET-HEATING FURNACE (QUIGLEY SYSTEM).

To face page 47.

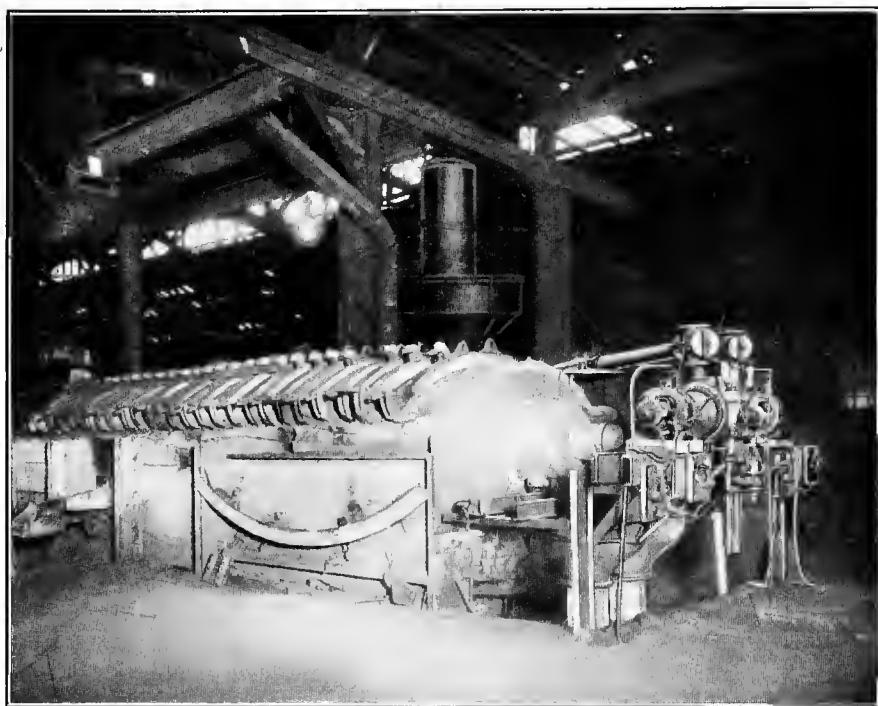


FIG. 15.—TYPE OF AMERICAN MALLEABLE IRON MELTING FURNACE ARRANGED FOR PULVERISED COAL FIRING.

of the furnace. 30 per cent. as hard or soft stalactites on the roof, and 10 per cent. as fine dust in the charging end of the furnace and in the flues.

Opinions of Users.

(26) "No trouble with the ash now that the combustion chamber arrangements have been altered, the ash in the 'hot' zone is run off as a liquid slag, in the next zone the ash adheres to the roof of the furnace in hard stalactite formation. Then comes a zone where ash is softer but still adheres to the roof. At the charging end, the ash, as light dust, settles over the billets and at the sides of the furnace."

(27) "The hard stalactites are dislodged and blown into heaps for removal, the soft ash and dust is simply blown into the flues by air jets."

(28) "The ash slag which is thrown down in the combustion chamber before the bridge wall, is removed once a week by dropping the fire bars originally used when the furnace was hand-fired."*

(29) "In the continuous billet-heating furnaces the amount of coal burned in powdered form is only 140 lbs. per ton of steel, and can get down to 125 lbs., but the higher figure is a conservative overall average. These furnaces are to serve the rolling mill which is laid out for a capacity of 50,000 tons of finished product per month."

HEAVY FORGE FURNACES.

Disposal of Ash and Slag.

The bulk of the ash is deposited in the actual heating chamber, only a small proportion finding its way into the flues and up the stack. No trouble is experienced in running off the slag from the furnace.

Opinions of Users.

(30) "Very successful for all their heavy work, but not for armour plate on account of the ash deposit on the work. This, in a measure, was also found to be a drawback for pressed-steel wheelmaking, the ash settling on the steel blanks formed a hard scale which spoilt the dies and matrices and consequently the accuracy of the work was destroyed."

(31) "For the same reason, armour plate could not be rolled with this covering of hard ash slag."

(32) "In spite of these difficulties the new pressed-steel shop would be equipped with powdered coal furnaces in view of the present high cost of fuel and shortage of supplies."

(33) "Several of the shops had repeatedly sent in requests to have their furnaces converted to powdered coal firing, as against hand firing. The 'average' saving over hand firing was at least 20 per cent. in coal alone."

(34) "Very uniform heat in powdered coal-fired furnaces, and the men preferred this system to any other, the working of the furnaces being easy and the quality of the work better than in gas or hand-fired furnaces. There was undoubtedly a great saving in labour as against hand firing."

(35) "With hand firing, one man is required to attend to the stoking of the furnace; with powdered coal, the operator of the furnace looks after his own burner regulation."

(36) "No men required to clear away ashes."

* The fire bars are covered with a layer of ashes.

(37) "In order to increase the output of No. 1 hammer, two hand-fired heating furnaces were used. Since changing over to powdered coal firing the hammer can be kept up to full output with one furnace."

(38) "In one furnace, when hand-fired, the coal consumption was 265 lbs. per ton of steel; with powdered coal this figure has been cut down to 150 lbs., including pulverising losses."

The billets heated in the furnaces inspected were for heavy gun forgings.

(39) "Powdered coal furnaces working very satisfactorily, but much prefer oil firing for this work. Oil, however, is now too costly, so that all furnaces have been changed to firing by means of powdered coal."

"The output of this forge plant is equal to the whole of the other plants operating in America, about 60,000 tons per annum."

"The forgings average about 26,000 lbs. each, and a maximum weight of 45,000 lbs."

LIGHT FORGE FURNACES.

Disposal of Ash and Slag.

In these instances where there are generally no means of drawing off the ash other than by suction systems for collection and removal of ash dust as it emerges from the mouth of the furnace, more difficulty is experienced. The first dust in such cases is found all over the machines and building structure, and it becomes a nuisance.

Efficient means for its removal have not yet received much attention, but at all events there should be no difficulty in making decided improvements in some of the existing plants.

Opinions of Users.

(40) "Coal per ton of steel heated to forging temperature, 458 lbs."

(41) "Have turned down powdered coal for small forging furnaces; too much time taken to get the furnaces away in the morning and cost of coal preparation makes the preposition too expensive for this work."

PILING, BUSHELLING AND SKELP WELDING FURNACES.

Disposal of Ash and Slag.

Since 60 per cent. of the ash is usually fused and collected in the combustion chamber from which it is cleared away periodically by dropping the bars supporting the ash bed on which the slag is deposited, ash carried over into the heating chamber will be fused and will run off in a semi-liquid form. The remainder, or infusible fine particles of ash, escape to the flues and so to the chimney. A small quantity of ash slag will always adhere to the pile, dripping off the latter before the rolls are reached.

Opinions of Users.

(42) "Saving effected in the powdered coal-fired furnaces is 3 per cent. in loss of metal as compared with the gas-fired furnaces. This represents an actual saving in money of nearly £4,167 (\$20,000) per month."

(43) "Natural gas per ton of steel was about 9,000 cubic ft., equivalent to one-third of a ton of the coal now being used. The amount of coal used in the bushelling furnaces is 450 lbs. per ton of steel rolled."

(44) "The amount of coal in powdered form per ton of steel heated for rolling is 500 lbs."

PUDDLING FURNACES.

Advantages Claimed.

Pulverised coal has introduced a method of heating by which the puddled iron can be worked up by the puddler with uniformity and speed, the output of furnaces being a maximum when compared with any other method of firing that has been tried out in some of the American works.

Disposal of Ash and Slag.

From 60 per cent. to 70 per cent. of the ash contained in the coal should be thrown down in a completely or semi-fused state in the combustion chamber which is arranged in a manner similar to that for piling furnaces. (Q.V.) Some of the ash forms a covering on the metal and is raked off, whilst the remainder passes away to the stack or is collected in the flue leading to the waste heat boiler.

Opinions of Users.

(45) "Furnaces used to take 3,000 lbs. of coal per ton (2,000 lbs.) of iron; with powdered coal only 1,200 lbs. of coal are required."

"It is intended to apply this system to some 80 furnaces, each turning out puddled blooms of 700 lbs. weight per heat."

This will mean a saving of some £29,167 (\$140,000) per annum, and the total capital outlay for this powdered coal equipment will be about £41,667 (\$200,000).

(46) "Have 31 puddling furnaces on powdered coal and now obtain 5 heats easily where only 4 heats were possible when the furnaces were hand-fired. Each heat now takes under two hours, blooms weighing 250 lbs. each. Saving in coal is certainly 40 per cent. over hand firing."

SHEET AND PAIR FURNACES AND ANNEALING FURNACES.

Advantages Claimed.

The application of pulverised coal firing has been most valuable. By this means not only is a constant temperature obtained within the furnace but, as against hand-fired furnaces, the best heat can be maintained for any length of time without any more attention than to see that the coal-feed and air-supply motors are running. It is also definitely found that annealing boxes last very much longer owing to absence of oxidation. Loss in actual metal from oxidation, both as regards boxes and the sheets or articles to be annealed, is often considerable, and savings effected by the introduction of pulverised coal firing ran into many thousands of pounds per annum at one works visited.

For sheet and pair furnaces it is claimed by actual owners and users of powdered coal fired furnaces that the reduction of "stickers" is very marked; that the sheets are softer and can be put through the rolls a greater number of times, without reheating, than was the case when the furnaces were fired by means of natural gas. This fact is appreciated by the men, who are thereby able to turn out a greater tonnage with fewer wasters than heretofore. Rolls require polishing but once per shift instead of frequently as when rolling metal heated in gas or oil fired furnaces.

Disposal of Ash and Slag.

In sheet and pair furnaces a small quantity of the ash may form into a sticky mass at the burner inlet whence it is removed by means of

scrapers. The bulk of the ash remains unfused and passes into the flue or escapes at the furnace door where means should be provided for exhausting the dust as it emerges.

In annealing furnaces the ash remains in the form of fine powder which settles over the boxes, on the floor, and in the flues. Its removal therefrom is an easy matter.

Opinions of Users.

The advantages claimed are those actually obtained by users. In no other specific furnace application is opinion so unanimously in favour of powdered coal firing as that expressed in relation to sheet and pair furnaces and annealing furnaces.

(47) "The amount of coal in powdered form per ton of finished plate is 290 lbs. When on hand firing the consumption of coal was about 350 to 450 lbs., according to the quality of the coal used."

(48) "Powdered coal firing for sheet and pair furnaces reduces stickers by 60 to 75 per cent. Sometimes a whole turn is run without a single 'sticker.' Men like the system on this account, for their output per shift is greatly increased, and they get paid on output of sound sheet."

(49) "Owing to the perfect reducing atmosphere in the furnaces it is only necessary to polish the rolls once every turn; previously it was often necessary to do this after every heat."

(50) "In the annealing furnaces the ash from the powdered coal protects the welded annealing boxes from which double the life is now obtained."

(51) "Have used coal with 22 per cent. ash, but the ash does not stick to the plates and will not 'roll in.'

(52) "Annealing furnaces used to be fired by natural gas, now that powdered coal is used it takes 12 to 15 hours to bring up the furnaces to annealing heat (1,600° F.), whereas previously it took from 17 to 24 hours."

(53) "The comparison between the cost of running the annealing furnaces with the three fuels, natural gas, fuel oil, and powdered coal shows the following cost per month:—

Natural gas, 14,000,000 cu. ft., at 1s. 1.5d. (27 cents)	£787 10s. (\$3,780)
--	---------------------

Fuel oil, 105,000 gallons, at 4d. (8 cents) ...	£1,750 0s. (\$8,400)
---	----------------------

Powdered coal, 525 tons, at £1 0s. 10d. (\$5.00) ...	£547 0s. (\$2,625)"
--	---------------------

"The cost per ton for powdered coal includes all charges except depreciation and interest on capital."

(54) "With hand firing, 2 lbs. of annealed castings required 1 lb. of coal; with powdered coal, 6 lbs. of castings are annealed with 1 lb. of coal, and the annealing is much more uniform."

(55) "Powdered coal has been used on the 13 annealing furnaces for the past 14 years. The temperature in the ovens is 1,600° F., the furnaces reaching this temperature in 72 hours coal consumption, 670 lbs. per ton of castings. Annealing boxes last from 7 to 10 weeks with proper air and coal adjustment. Have had no explosion whatever during the 14 years working with powdered coal."

MALLEABLE IRON MELTING FURNACES.

At one works in America at which the hand-fired malleable iron reverberatory melting furnaces have been changed over to pulverised-coal firing, there are five furnaces. As hand-fired, four of these had a capacity

of 20 tons and one of 13 tons per 24 hours, and the melting ratio was $2\frac{1}{2}$ lbs. of metal to 1 lb. of coal.

In making the change to pulverised-coal firing the hand-fired grate area was covered over and the bath area extended, thus increasing the capacity of the furnace by about $33\frac{1}{3}$ per cent.

The melting ratio obtained with pulverised coal is now $3\frac{1}{2}$ lbs. of metal to 1 lb. of coal, and certain labour required (2 men per 24 hours) for operating under hand-firing conditions has been eliminated. A complete log sheet for a 24-hour operation is given below.

Log of Test on Malleable Iron Melting Furnaces.

19th September, 1919.

Time.	Total Coal Lbs. Two Burners.	Remarks.
1:30 a.m.	9·5	No. 1 burner on; stack damper wide open.
:55	18	No. 2 burner on.
2:05	20	
:15		Charge dripping at south peep-hole; air ratio 185·1.
:45	18·6	Air ratio—199 to 1.
3:10		Stack damper closed 6".
:20		Air ratio—181 to 1; charge dripping at skim door.
4:15		Charge all down at front end.
:30		Rabbling charge, levelling up.
:45		Charge all loose and practically level.
5:30		Rabbling charge.
6:00		First skim made.
:30		Finished skim, closed stack damper 2", making 8" total.
:44		Second skim made.
7:07		Finished second skim.
:26		First test sample taken, slight mottle, fine grain.
:37		Added 30 lbs. ferro manganese.
:41		Opened stack damper 4", making 4" closed total.
:49		Took second test sample.
8:00		Ready to tap, but held up waiting for No. 2 furnace pouring off.
:08		First tap made.
:10	12·9	Damper closed 3", making total of 7" closed.
:20		Damper closed $1\frac{1}{2}$ ", making total of $8\frac{1}{2}$ " closed.
:26		Second tap hole opened.
:55		Shut off coal; closed No. 1 tap hole.
9:02		Finished tapping.
Kind of coal used—Pulverised slack.		
Total coal used—1:30 a.m. to 8:55 a.m.—7 hrs. 25 mins.— 7,843 lbs.		
Average rate of coal consumption $7843/739=1,061$ lbs.		
Furnace—Cold on starting up.		
Furnace—in good condition after heat.		
Mechanical equipment—Satisfactory—no delays.		
Melting ratio—3·82 to 1.		
Total time elapsed—7 hrs. 32 mins.		
Stack damper was used as noted in the log.		

Time.	Total Coal Lbs. Two Burners.	Remarks.
9:30	12·9	Both burners on; air ratio 220·1, stack damper closed 9".
:45	15·6	Air ratio—181·1.
10:10		Poling charge and levelling up at south peep-hole; charge nearly all down at front.
11:40		Poling charge at north side.
:50		Charge nearly all melted at front end.
12:10		Poling charge at front end, getting mushy at rear end; raised stack damper 1", or 8" closed total.
:45		Poling charge; not yet fluid at front.
1:05 p.m.	18	Air ratio floating now, little pasty at rear.
:30		Charge all 170·1; loosening up charge at back.
2:05		First skim taken.
:20		Finished skim; skim was good, firm and smooth.
:45		Second skim taken.
:50		Finished skim.
:55		First sample taken; slight mottle, grey fracture.
3:10		Skimming.
:14		Finished skimming, second sample taken.
:20		Added 30 lbs. ferro manganese, bungs are tight, no gas burning on top.
:35		Third sample taken, not quite ready.
:45		First tap made.
:50	12·9	Lowered damper 2", making total of 10", air ratio 152 to 1.
:55		Second tap opened.
4:25		Shut off coal, delayed 10 mins. waiting for moulds.
:30		Last tap.

Kind of coal used—Pulverised slack.

Total coal used—9:30 a.m. to 4:25 p.m.—6 hrs. 55 mins.—6,736 lbs.

Average rate of coal consumption—6736/6·9—976 lbs.

Furnace—Hot on starting.

Furnace—Side walls for 10' 0" at front end had to be rebuilt after this heat.

Mechanical equipment—Satisfactory.

Melting ratio—4·45 to 1.

Total time elapsed—7 hrs.

Stack damper was used as noted in the log.

The heat was long on account of the low coal used from 9:45 a.m. to 1:05 p.m.

Regarding ash accumulation in melting furnaces, when using pulverised coal as a fuel a certain percentage melts and falls upon the slag and is taken out of the furnace when the metal is skimmed (this does not affect the quality of the metal in any way). There is an accumulation of slag in the pocket of the furnace located between the bridge wall and the damper, which, if allowed to accumulate for three days, would affect the draft of the furnace, but the practice is to remove this every day after the two-heat

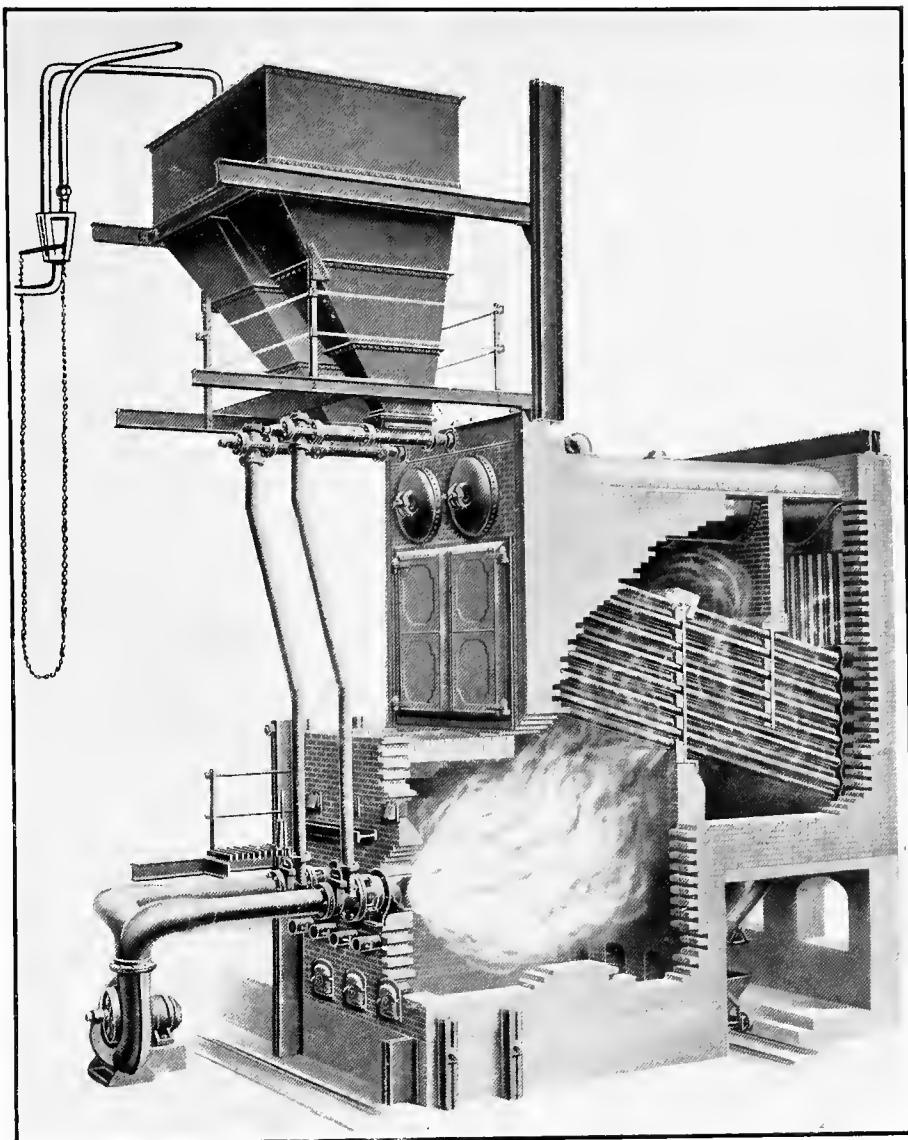


FIG. 16.—BABCOCK & WILCOX WATER TUBE BOILER AS ARRANGED FOR POWDERED COAL FIRING.

(Fuller System.)

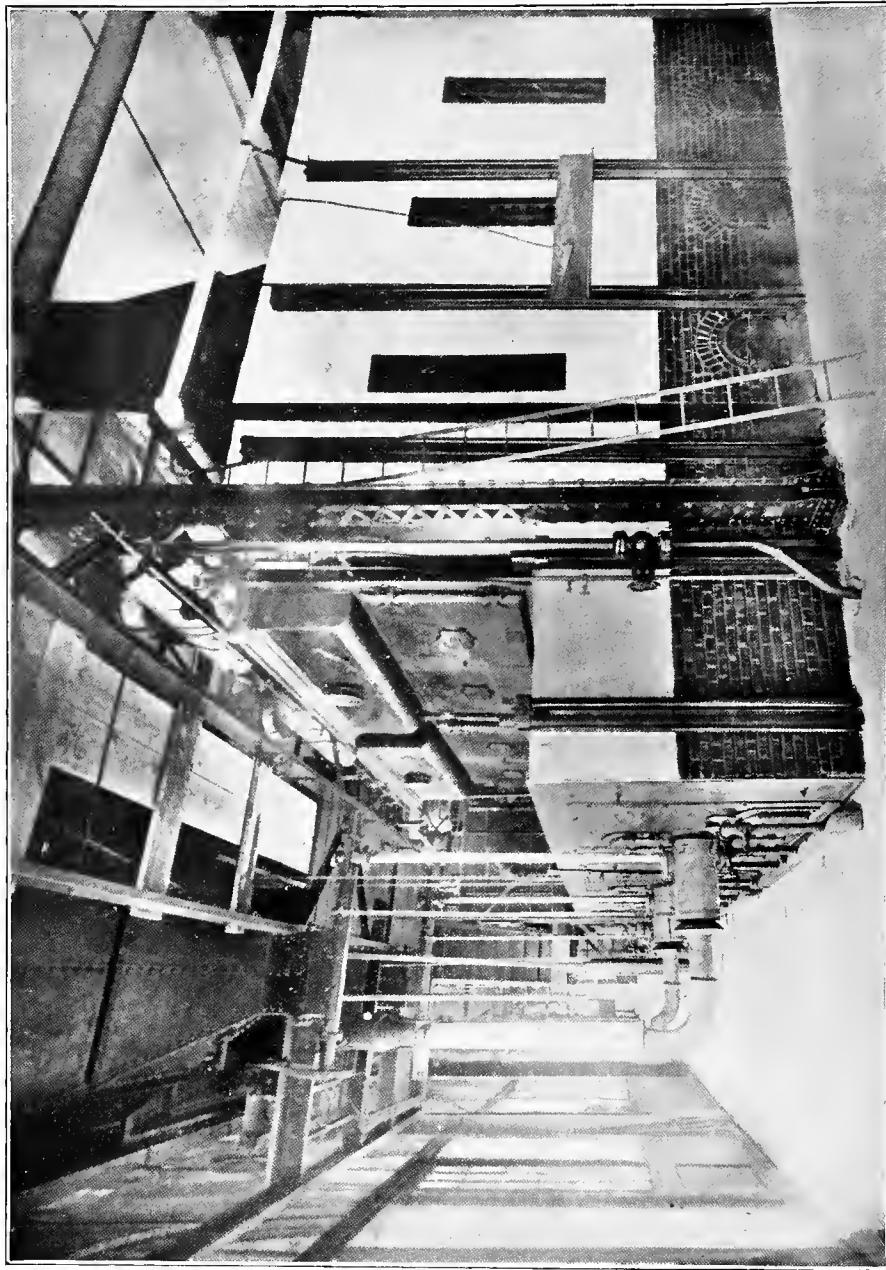


FIG. 17.—BOILER PLANT AT MISSOURI, KANSAS AND TEXAS RAILWAY SHOP (FULLER SYSTEM).

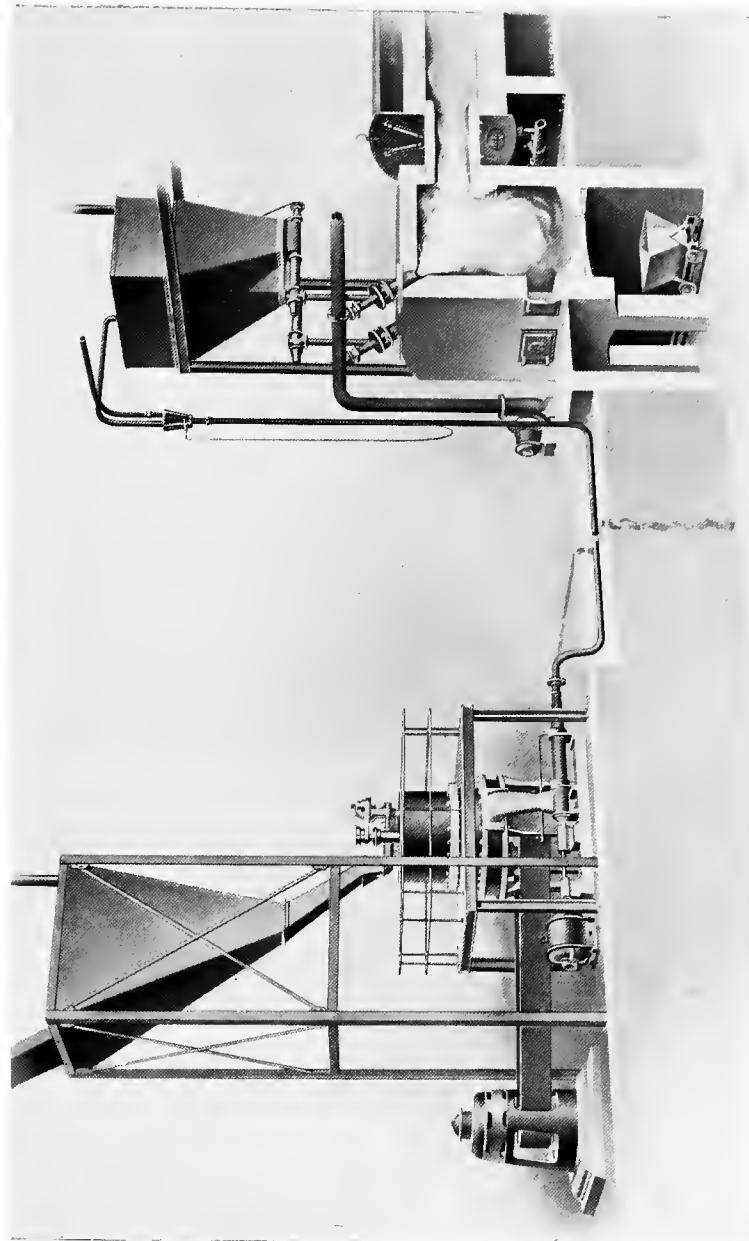


FIG. 18.—SUGGESTED ARRANGEMENT OF PULVERISED COAL EQUIPMENT FOR LANCASHIRE BOILER.

To face page 53.

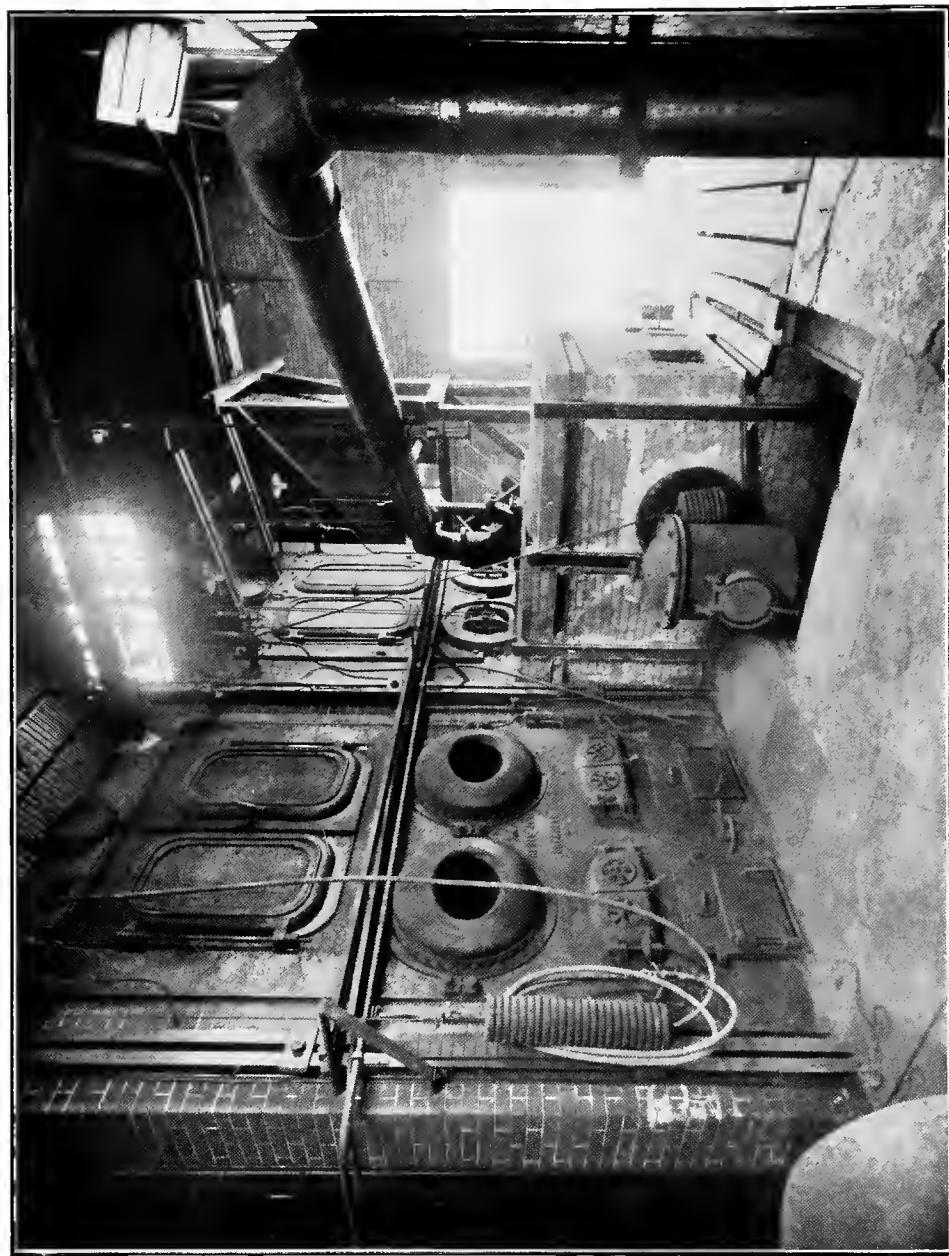


FIG. 18A.—ADAPTATION OF PRODUCER GAS-FIRED BOILER IN FRANCE UTILISING THE EXISTING COMBUSTION CHAMBER (SLIGHTLY MODIFIED TO PROVIDE "DRY ASH" REMOVAL FACILITY) AND FOR BURNING LOW VOLATILE ANTHRACITE "FINES" (0-2mm.). INSTALLATION CARRIED OUT ON THE BERGMAN SYSTEM.

run. The quantity of slag removed per day is equal to about 10 per cent. of the ash in the coal and the coal analyses 8 per cent. ash. The slag breaks up very easily with the small hammer and is shovelled out of the furnace. The general appearance is black and glassy and of light weight with only a trace of carbon.

RIVET HEATING AND NUT AND BOLT FURNACES.

Disposal of Ash and Slag.

See remarks as for Light Forge Furnaces, page 32.

Opinions of Users.

(56) "Would remove the powdered coal equipment from these shops if any other fuel were available. Too much ash in the shop, causing heavy wear and tear on the machinery working in the buildings."

(57) "Coal required for heating iron for making stay bolts is about 1,800 lbs. per ton."

GALVANISING AND TINNING FURNACES

Advantages claimed.

The use of pulverised coal ensures as even a temperature as when oil or gas is used. There are no occasions when the metal is either too hot or too cold, which is often the case when kettles are hand-fired with coal.

Disposal of Ash and Slag.

For all moderate or low temperature work, where flues and chimneys can be used and on account of the moderate heat, the ash is not fused but is deposited in the flues and at the bases of the chimneys. As the ash is generally in the form of a very fine powder, no difficulty is presented in its removal.

Opinion of Users.

(58) "The savings effected by the use of powdered coal are considerable, and lie in the following directions:—

"Saving in coal.

"Saving in metal lost. On sheets through the mill, and in the galvanising or tinning bath.

"Saving in labour.

"Saving in acid for pickling.

"Saving in zinc and tin."

(59) "In the tin-plate furnaces with hand firing the coal used was 500 to 600 lbs. per ton; with powdered coal the consumption of coal is 280 to 300 lbs. per ton."

(2) STEAM BOILERS.

The past period of five years has seen much progress made in the application of pulverised coal to the firing of steam boilers. The many and serious difficulties previously encountered have been overcome; one of the greatest achievements of the last few years being the satisfactory elimination of the ash problem. Metallurgical furnaces offered an easier field in which to investigate these difficulties, and it is, therefore, found that greater strides have been made in application to melting and heat treatment furnaces than to steam-raising plant.

The advances made in the proper control of gas velocities, combustion areas and methods of dealing with ash and slag in metallurgical furnaces, brought with them the solution of the ash and slag difficulty in connection with steam boilers.

At first isolated tests on single or two boiler units were run at several American works. These experiments gave such promising results that the directorate of the Missouri, Kansas and Texas Railway decided to equip their eight O'Brien boilers with coal-dust burners. This company was therefore the first to put down a comprehensive coal pulverising plant for purely boiler house work.

The Fuller Engineering Company carried out this installation and it is greatly due to their efforts and success in this particular plant that so much interest in pulverised coal firing is now being shown by power house engineers.

Messrs. Stone and Webster, consulting engineers, of Boston, Mass., introduced this system at the power station of the Puget Sound Traction Company some three years ago. The boiler capacity of this station is 4,100 h.p.

This may be taken as having been the first decisive step in the direction of using pulverised coal in the boiler house of a public supply power station, and has now been followed at Milwaukee, where the new 200,000 k.w. station is laid out for the use of pulverised fuel for firing the boilers.

In the early days of boiler firing by this means ash and slag accumulated to such an extent on the boiler tubes, over flue sheets, in the smoke-box and in the combustion chamber that first experiments gave little promise of success; and in order to overcome this very real trouble, Mr. Bettington designed his special vertical water tube boiler for use with pulverised coal. In this design special provision was made for running off the ash slag in liquid form.

Mr. R. Turnbull Mawdesley, in an article on the equipment of the municipal electric supply station of Johannesburg, S.A., makes reference to the Bettington Boilers installed at this plant. (See "Electrical World," March 11th, 1916.)

In his article Mr. Mawdesley sums up the advantage of using pulverised coal in the following remark:—"It is possible to put this boiler on the range within 25 minutes of lighting up from dead cold. As soon as the fuel is shut off the fire is extinguished like a gas jet and there are practically no stand-by losses."

Pulverised coal can now be applied with undoubted success to any type of fire or water tube boiler, and there is no reason why this method of firing cannot be adopted for Cornish, Lancashire, and in fact all types of standard boilers. A boiler such as the Bettington is no longer necessary in order to obtain perfect results.

It was found, after much experimenting, that by cutting down the velocity of hot gases in the combustion chamber to a minimum, the bulk of the ash could be removed before the hot gases reached the boiler tubes. Only a small percentage of the coal ash in the form of dry dust now reaches the boiler tubes and flues.

The dust which settles on the boiler tubes is so light and fine that it can be dislodged by blowing with the mouth. A steam jet will clear the deposit in a few minutes, and ash dust in the flues is cleaned out periodically without any difficulty. Liquid slag or caked ash is dealt with in the combustion chamber, the degree of hardness of this ash depending upon its degree of fusibility.

A description of what may be called the pioneer boiler house plant, at the repair works in the Missouri, Kansas and Texas Railway, is given

in the original report, the account of which was taken from "Metallurgical and Chemical Engineering," September 15th, 1916, and is again reproduced. This application records the first comprehensive and successful tests carried out on pulverised coal fired boilers, with a wide range of fuels:—

"When during the winter of 1912 the natural gas supply was limited in quantity and fuel oil hard to obtain in Kansas, the Missouri, Kansas and Texas Railway Company officials decided to investigate other methods for generating steam in their boilers at the power house of their new shops at Parsons, Kan., where eight 250 h.p. O'Brien boilers of the Heine water tube type were installed with equipment for using only natural gas and oil fuel. Some of the other fuels available in the district which would be within an economical range as to cost delivered at their plant were soft coals from the mineral mine in Kansas, McAllister and Lehigh mines in Oklahoma, and lignite from Texas, with the following Government analyses as received:—

Kind of Coal.	Fixed Carbon.	Volatile Matter.	Ash.	Moisture.	B.Th.U. Value.
Mineral ...	45·22	26·39	20·38	8·01	10,640
McAllister ...	47·07	32·37	14·29	6·27	11,837
Lehigh ...	41·40	31·28	19·29	8·03	11,200
Lignite ...	25·50	33·95	7·58	32·97	7,548

"The sulphur separately determined ranged from approximately 3 to 5 per cent. in the various soft coals."

"Owing to the ash and moisture content of these available fuels, it was determined by the Missouri, Kansas and Texas Railroad officials to investigate the method of using these fuels in a pulverised form, as they were aware of the fact that pulverised bituminous coal had been in constant use in the cement industry, in a major portion of the plants throughout the country, and on many industrial furnaces for years, and the method of preparing this fuel eliminated almost all of the moisture before injection into the furnace, thereby obtaining the highest possible B.Th.U. value in the fire-box from the fuel, instead of the loss that would obtain if used in the old way, by hand-firing or stokers, with fuel ordinarily received from the cars, as it was found cheaper to drive off this moisture in driers designed for the purpose."

"In the early part of 1916 orders were given to proceed with the work. The work was started in the spring, completed, and put into successful operation on August 1st, 1916."

"Various tests were made with the different fuels mentioned above, and all of them were burned with entire success, showing no destructive effect on the fire-brick wall of the furnace, but giving a most effective distribution of the heat throughout the several passes of the boiler and exceptional heat absorptive effects throughout the heating surface of the boiler with low stack temperatures. No deposit of ash settled anywhere in the boiler but what was readily dislodged with an ordinary air blast. The evaporation obtained with 16 per cent. CO₂ in the stack was 10·7 lb. of water per pound of combustible from and at 212 deg."

A resumé of the tests carried out on these boilers was printed in "Power," September 11th, 1917, and the tabulated results are reproduced here:—

TESTS ON BOILERS AT THE MISSOURI, KANSAS AND TEXAS R.R. SHOPS AT PARSONS, KANSAS, FIRED WITH PULVERISED COAL.

No. of Test.	Kind of Coal.	Rated Boiler power.	Horse-power.	Duration of Test, Hours.	Steam Pressure by Gauge, Lb.	Temperature of Feed Water, Deg. F.	Factor of Evaporation.	Flue-Gas Analysis.				Prof. Analysis Dry Coal.			Equiv. Evap. from and at 212 per Lb. Coal as Fired.	Equiv. Evap. from and at 212 per Lb. of Dry Coal.
								CO %	O %	CO %	N %	Vol. %	Fixed Car. %	Ash. %		
1	Cherokee Mineral Slack ...	191	1 hr. c min.	126	177	1·0795	12	8	0	80	28	49	22	6·32	6·38	
2	Texas Lignite ...	191	2 4	127·4	183·6	1·0728	10	10	5	79·5	42·5	32	9·5	7·17	8·54	
3	McAllister ...	191	2 12	127	180	1·0764	10	9·5	0	80·5	31·3	50·1	15·1	8·77	8·85	
4	Texas Lignite ...	191	1 30	118·1	182	1·0736	10	11	0	79	47·1	35·4	10·5	7·31	7·86	
5	Texas Lignite ...	161	1 13	130·6	182·5	1·0743	12·5	8·5	0	79	47·1	35·4	10·5	7·26	7·81	
6	Cherokee Mineral Slack ...	382	1 24	126	170	1·0867	10	11	0	79	28·4	48·7	21·9	7·18	7·27	
7	Cherokee Mineral Slack ...	191	2 0	123	187	1·06875	13·5	7·5	0	79	28·4	48·7	21·9	6·9	6·97	
8	Cherokee Mineral Slack ...	191	6·58	126·6	174·4	1·0822	10·7	9·3	0	80	28·4	48·7	21·9	8·38	8·46	
9	Texas Lignite ...	191	4·30	137·5	166·9	1·0562	14·75	5	0	81·16	61·52	24·72	13·76	4·958	6·305	
10	Cherokee Mineral Slack ...	191	4·0	135	165·8	1·0559	14·8	3·5	0	81·9	32·41	49·57	18·02	6·824	7·306	
11	Kansas Semi-Anth.	191	3·30	135·5	178·1	1·0434	15·8	3·5	0	81·6	22·29	59·94	17·77	8·657	9·063	

No. of Test.	Kind of Coal.	Combined Boiler and Furnace, B.th.u. per Lb. Dry Coal.	Efficiency	Draft.			Temperature of Flue Gases, Deg. F.	Total Wt. Coal as Fired, Lb.	Moist. in Coal as Fired, %	Total Dry Coal Fired, Lb.	Total Combustible, Lb.	Equiv. Evap. from and at 212 per Hour.	Per Cent. Rated Capacity Developed.	
				Air In.	In Furnace.	At Boiler Damper.								
1	Cherokee Mineral Slack ...	53·9	11,580	11,580	11,580	11,580	0·25	544	1,014	1	1,004	781	6,420	97
2	Texas Lignite ...	75·5	11,250	11,250	11,250	11,250	0·28	491	1,927	16	1,620	1,487	6,690	101
3	McAllister ...	67·8	12,630	12,630	12,630	12,630	0·28	588	2,062	1	2,051	1,739	8,240	120
4	Texas Lignite ...	67·8	11,250	11,250	11,250	11,250	0·262	473	1,746	7	1,623	1,440	8,520	123
5	Texas Lignite ...	67·4	11,250	11,250	11,250	11,250	0·265	501	1,612	7	1,500	1,380	9,550	143
6	Cherokee Mineral Slack ...	61·0	11,380	11,380	11,380	11,380	0·242	470	3,540	1	3,500	2,730	17,450	138
7	Cherokee Mineral Slack ...	59·0	11,580	11,580	11,580	11,580	0·256	576	3,560	1	3,525	2,745	12,280	186
8	Cherokee Mineral Slack ...	71·5	11,580	11,580	11,580	11,580	0·23	446	6,617	1	6,560	5,100	7,950	125
9	Texas Lignite ...	57·32	10,675	0·55	0·082	0·092	0·092	581	6,748	17·06	5,598	4,825	7,844	119
10	Cherokee Mineral Slack ...	58·00	12,185	0·41	0·051	0·055	0·055	534	4,692	1·06	4,644	3,808	8,482	129
11	Kansas Semi-Anth.	69·64	12,625	0·40	0·058	0·000	0·000	624	3,500	0·8	3,489	2,868	9,034	137

These tests were carried out for the Railway Company by Mr. Joseph Harrington, combustion engineer, Chicago.

A list of some of the boiler installations in America, together with tests and notes upon the various fuels used in pulverised form, given below, has been taken from a paper by Mr. Scheffler and Mr. Barnhurst, which paper was read at Detroit in June, 1919, before the American Society of Mechanical Engineers.

American Pulverised Coal-Fired Boiler Installations.

Date of installation.	Name of company.	Location.	No. of boilers.	Horsepower rating and make of boilers.	Furnace design, per cent. of rating.	Coal used.
Aug. 1916	M. K. & T. R.R. ...	Parsons, Kan	8	250 O'Brien	125-150	McAllister Cherokee slack, Kan. semi-anthracite, Texas lignites, San Bois coal, Oklahoma..
Nov. 1916	American Locomotive Co.	Schenectady, N. Y.	1	300 Franklin	150	
June 1918	U. S. Verde Extension Mining Co.	Verde, Ariz.	2	439 Stirling	150	Gallup and semi-lignite.
Feb. 1918	Ash Grove Lime & Cement Co.	Chanute, Kan.	1	371 Heine	150	Various grades of Kansas coals.
June 1918	Garfield Smelting Co.	Garfield, Utah	2	371 Stirling	150	Wyoming lignite Wyopa, Wyoming lignite. Keystone, Utah, bituminous from various mines.
Nov. 1918	Puget Sound Light and Power Co.	Seattle, Wash.	10	4-500 B. & W. 2-600 B. & W. 3-400 B. & W. 1-500 B. & W. 250 Rust	150	Benton buckwheat, Washington bituminous lignite and sub-bituminous.
Nov. 1917	Sizer Forge Co.* ...	Buffalo, N. Y.	5		125	Pittsburgh and Pennsylvania.
Mar. 1919	British Columbia Sugar Refinery Co.	Vancouver, B. C.	13	2-504 Badenhausen 2-250 B. & W. 9-110 HRT	150	Vanconver, B. C., bituminous and lignite.
July 1918	Milwaukee Electric Railway & Lighting Co.	Milwaukee, Wis.	5	468 Edge Moor	150	Indiana and Illinois bituminous, Pittsburgh and Yowghigheny.

American Pulverised Coal-fired Boiler Installations.

Date of installation.	Name of company.	Location.	No. of boilers.	Horsepower rating and make of boilers.	Furnace design, per cent. of rating.	Coal used.
Mar. 1919	Allegheny Steel Co.	Allegheny, Pa.	1	333 Wicks	...	Pittsburgh coals.
June 1919	Inland Steel Co. ...	Chicago Heights, Ill.	1	250 Heine	150	Illinois bituminous.
June 1918	Pacific Coast Coal Co.	Seattle, Wash.	10	160 HRT	...	Benton buckwheat.
			8	100 HRT	...	Washington, bituminous, lignite and sub-bituminous.
Nov. 1918	Susquehanna Collieries Co.	Lykens, Pa.	1	250 B. & W.	200	All grades of anthracite washery culm, mine dirt, No. 3 buckwheat, Lykens slush, Lytle slush.
June 1919	Lytle Coal Co. ...	Lytle, Pa. ...	6	333 B. & W.	200	All grades of anthracite washery culm, Lytle slush.
May 1919	Garfield Smelting Co. (2nd installation).	Garfield, Utah	4	371 Stirling	150	Wyoming lignite, Wyops, Wyoming lignite, Keystone, Utah, bituminous from various mines, Obtain and use coal from Pacific Coast Coal Co.
Sept. 1918	L. S. Smith Bldg. ...	Seattle, Wash.	2	1-300 B. & W.	...	Obtain and use coal from Pacific Coast Coal Co.
Sept. 1918	Crystal Natatorium	Seattle, Wash.	2	1-200 B. & W.	...	Obtain and use coal from Pacific Coast Coal Co.
Sept. 1918	Crystal Natatorium	Seattle, Wash.	2	72 × 18 HRT	...	Obtain and use coal from Pacific Coast Coal Co.
Sept. 1918	Pacific Coast Coal Co. ...	Seattle, Wash.	12	72 × 18 HRT 2-250 Wicks 2-125 Ames (72 × 16) 6-125 Chandler & Taylor. 2-125 Casey Hedges	...	Obtain and use coal from Pacific Coast Coal Co.

Tests carried out on American Pulverised Coal-Fired Boilers.

Date of test.	Location of plant.	Duration, hr.	Coal used.	Effici- ency main- tained, per cent.	B.th.u. per lb. of Coal as fired.	Ash per cent.	Rat- ing, per cent.
Apr. 16, 1917	Seattle, Wash.	14·5	Renton buckwheat	77	10,000	11·60	122
Dec. 4, 1917	Chanute, Kan.	5	Kansas bituminous	72	11,996	17·7	125
Dec. 12, 1917	Chanute, Kan.	5	Kansas bituminous	83·94	12,500	18·25	125
Jan. 28, 1918	Chanute, Kan.	(25 days)	Kansas bituminous	78·1	11,435	—	100
Apr. 26, 1918	Parsons, Kan.	6	Kansas bituminous	80·3	12,900	17·49	—
Apr. 28, 1918	Parsons, Kan.	6	Kansas bituminous	80·9	12,289	17·49	130·8
June 14, 1918	Milwaukee, Wis.	12	Illinois and Indiana screenings.	83·3	10,897	15·89	117·7
Nov. 5, 1918	Lykens, Pa. ...	10	Lykens No. 3 buckwheat anthracite.	84·2	12,530	16·92	135
Nov. 15, 1918	Lykens, Pa. ...	5	Lykens slush buckwheat anthracite.	81·2	13,653	11·09	142
Nov. 22, 1918	Lykens, Pa. ...	5	Lykens slush buckwheat anthracite.	85	12·7·3	18·04	146
Nov. 23, 1918	Lykens, Pa. ...	5	No. 3 buckwheat anthracite.	72·7	12,530	16·91	115
Dec. 2, 1918	Lykens, Pa. ...	5	Lytle slush anthracite.	75·3	12,753	23·92	188
Feb. 1, 1919	Seattle, Wash.	24	Issaquah screenings	78·5	11,660	14·31	126
Feb. 2, 1919	Lykens, Pa. ...	4	No. 3 buckwheat anthracite.	78·9	13,067	14·02	177
Apr. 7, 1919	Vancouver, B.C.	4	Nanaimo slack ...	83·3	9,364	28·4	125
Apr. 17, 1919	Vancouver, B.C.	5	Nanaimo slack ...	77·1	10,050	24·3	160
Feb. 3, 1919	Lykens, Pa. ...	5·5	No. 3 buckwheat anthracite.	78·9	12,530	14·00	—
Sept. 24, 1918	Verde, Ariz. ...	(6 days)	Gallup, New Mexico	79·5	10,680	14·31	155

The departure introduced by Messrs. Stone and Webster at Seattle, Washington, in adopting powdered coal firing for steam raising was a step of far-reaching importance, but the test figures then obtained have not been reprinted herein because results of more recent date are now available.

In place thereof test figures for a boiler plant at the British Columbia Sugar Refinery Works have been substituted.

BOILER TEST AT VANCOUVER, B.C.

Date : April 7th, 1919.

Location : B.C. Sugar Refining Co., Ltd., Vancouver, B.C.

Make and Type of Boiler : Badenhausen Vertical Water Tube.

Object of Test : Efficiency ; Rate of Evaporation ; General Results.

Fuel.

Kind : Vancouver Island ; Nanaimo ; Bituminous ; Slack.

Analysis : Moisture of 1·1 per cent. ; VCM. 32·8 per cent. ; C. 37·7 per cent. ; Ash 28·4 per cent. ; B.Th.U. 9,634.

Pulverised : 81·1 per cent. through 200 Mesh. ; 95·25 per cent. through 100 Mesh.

Weight of Coal as Fired : 16,824 lbs.

Water.

Weight of Water Fed to Boiler : 122,345 lbs.
 Temperature Feed Water Entering Boiler : 177 deg.
 Temperature Feed Water Entering Economiser : 85 deg.

Steam.

Pressure by Gauge : 71 lbs.
 Temperature at Gauge Pressure : 317 deg. Fah.
 Superheat : Boiler designed for 10 deg. or 12 deg. superheat, but not considered in this test.
 Factor of Evaporation : 1.160.

Hourly Rates.

Dry Coal per hour : 2,763 lbs.
 Water per hour actual : 20,390 lbs.
 Water per hour F. and A. 212 deg. : 23,652 lbs.
 Evaporation per hour per sq. ft. Water Heating Surface : 4.32 lbs.

Capacity.

Boiler Horse Power Developed : 727 H.P.
 Rated Boiler Horse Power : 600 H.P.
 Percentage of Rated Capacity Developed : 122 per cent.

Economy Results.

Actual Evaporation per lb. of Coal as Fired : 7.27 lbs.
 Equivalent Evaporation per lb. of Dry Coal F. and A. 212 deg. : 8.53 lbs.
 Equivalent Evaporation per lb. of Combustible F. and A. 212 deg. : 11.93 lbs.

Efficiency.

Combined Boiler and Furnace Efficiency Based on Coal as Fired : 85.0 per cent.

Flue Gases.

Temperature of Escaping Gases from Boiler : Average 500 deg.
 Temperature of Escaping Gases from Economiser : 385 deg.
 Analysis of Gases CO₂ by recording apparatus : Average 13 per cent.
 O by Orsat apparatus ; 6 to 8 per cent.
 CO by Orsat apparatus : None.

Smoke : Very light white haze.

Draft : Over fire $\frac{1}{4}$ in. ; At stack $\frac{5}{8}$ in. to $\frac{3}{4}$ in. ; Induced Draft.

Furnace Temperature : 2,200 deg. to 2,540 deg. ; Average 2,425 deg.

Information and test figures of the highest importance on this question of pulverised coal for boilers, also notes as to overall costs for coal preparation and comparative figures for mechanical stoker maintenance, have been published by Mr. John Anderson, Chief Engineer of Power Plant at Milwaukee. His statements and results are given at some length in view of their exceptional value.

EXCERPTS FROM A PAPER ENTITLED "USE OF PULVERISED COAL UNDER CENTRAL STATION BOILERS.

Read by Mr. JOHN ANDERSON, Chief Engineer of Power Plants of the Milwaukee Electric Railway and Light Company, before the Technical League of the Employees' Mutual Benefit Association, Milwaukee, February 19th, 1920.

The boiler tests were carried out under the direction of the Test Engineer and Superintendent of Power Plant and verified by Mr. Paul W. Thompson, Technical Engineer of Power Plants for the Detroit Edison Company.

This paper, report, and test figures are of special importance in view of the decision to instal pulverised coal plant for the new 200,000 k.w. super-power station at Milwaukee after tests carried out at the old station over a period of two years had demonstrated the possibilities of pulverised coal firing.

The chief reason for adopting this system, Mr. Anderson says, is that owing to "the recent heavy increases in price of coal any process which promised greater efficiency found a broad field opened up before it for application to stationary boilers. Previous to this time some work had been done in developing its use in locomotives, but the reasons for its application to stationary boiler furnaces and the small saving that might be effected with coal at a low price did not promise to offset the cost of pulverisation. Such conditions did not encourage the use of fuel in powdered form, therefore until the higher prices of the last three years forced economy in every direction," and that "with coal and air supplies easily adjustable, perfect fire control is assured, and it becomes at once obvious why coal is burned so efficiently in pulverised form.

In further explanation of this it is well to consider briefly the indications of efficient combustion applied to the steam boiler. Chief among these is the percentage of carbon dioxide, or CO_2 .

"The condition desirable is that with the percentage of CO_2 as high as practicable there should be no CO—a condition obtainable to a greater degree in a pulverised fuel furnace than in any other type.

"The percentage of CO_2 to be maintained in pulverised fuel practice is determined to a great degree by furnace limitations rather than combustion consideration. From 16 to 17 per cent. CO_2 in the flue gases is easily obtainable, but it cannot be maintained in actual operation due to exceedingly high flame temperatures that result and the consequent destruction of the brickwork. The temperature of the furnace, therefore, must be regulated by varying the volume of excess air.

"It is known that the combined efficiency of a boiler and furnace does not decrease when the fuel is poor, which condition does not hold true for the stoker. In the case of the stoker, the dropping off in efficiency is at a more rapid rate than the B.Th.U. value of the fuel would indicate as normal, and so much so, that the point is rapidly reached when proper combustion cannot be maintained.

"Operation of a pulverised fuel fired boiler, equipped with proper instruments can be varied to take big fluctuations in load over very brief periods of time. A heavy overload can be quickly taken on or dropped off by adjustment of the coal and air feeds, and without any waste of fuel as

always occurs under like conditions in stoker practice. No losses occur due to clinkering of coal or cleaning of fires, this condition of operation being entirely eliminated.

"Irregularities caused by change in quality and variation in size of coal, such as the fireman cannot successfully cope with on stokers, are also eliminated. Furnace conditions necessary to most economical combustion are more perfectly obtained and hence a horizontal combined efficiency curve is possible of approximate attainment.

"Due to its easily regulated coal and air supply and its perfectly controlled rate of combustion, the pulverised fuel furnace practically eliminates losses of combustible in ash. Ordinarily this loss is relatively large and varies according to the nature of the coal, type of stoker and the boiler load carried. In pulverised fuel practice the loss is very small and these variations do not occur.

"The ease with which the fuel feed and draft is controlled, the ability to take on and drop off heavy overloads in a brief time, the thorough combustion of the coal, and the uniformly high efficiency obtainable under normal operation constitute the chief advantages of pulverised fuel over other methods of coal burning.

"An additional economy is effected during banked boiler hours. Banking conditions when operating with pulverised fuel are somewhat different than those obtained in stoker practice. By stopping the fuel and closing up all dampers and auxiliary air inlets, a boiler fitted for use of pulverised fuel can be held up to pressure for several hours. The furnace brickwork having been heated to incandescence during operation gives off a radiant heat which is almost all absorbed by the boiler rather than escaping up the stack intermixed with an excess of cooling air. Radiation losses only occur as against radiation plus stack and grate losses in the case of the stoker.

"Commenting for a moment on the maintenance features of such a plant as has been described, it is the writer's (Mr. Anderson) belief, based on two years' operating experience, that the furnace brickwork in a pulverised fuel furnace will stand up equally as well as a stoker installation, with a very great advantage in favour of the former due to the elimination of all iron work in the furnace or anywhere near the high temperature zones of the boiler furnaces.

"The object of tests carried out was to obtain complete data on the pulverised fuel installation for the purpose of making comparison with stoker installation, no attempt being made to establish boiler room conditions other than those maintained during regular operation.

"The coal used, with the exception of the first day, when 100 per cent. Youghiogheny was used, the coal for the test was a mixture 50 per cent. each Eastern Kentucky and Youghiogheny screenings, running approximately 25 per cent. nut, 45 per cent. pea, and 30 per cent. slack. This coal is the same as is used in daily operation. The coal as supplied to the dryer after passing through disintegrator was approximately 50 per cent. slack and 50 per cent. small pea and nut, not any of the pieces being larger than one-half an inch.

"In the pulverised coal storage bins it was found that, during the first twenty-four hours of the test, moisture with its attendant difficulties was collecting in storage bins. Cold air draughts through windows alongside of the bins caused this condition by rapidly condensing the vapour in the entrained air. When the windows were tightly closed it was eliminated."

TEST DATA. November 11th—15th, 1919.

1. Number and kind of boilers	Five Edge Moor water tube boilers
3. Volume of combustion space, per boiler, cubic ft.....	1,678
4. Water heating surface, sq. ft., per boiler	4,680
5. Superheating surface, sq. ft., per boiler (approximate)	594
(a) Type of superheater	Foster
6. Total heating surface, sq. ft., per boiler	5,274
8. Duration, hours	99
9. Kind and size of coal. ... Mixture, 50 per cent. Yough. Scrgs. 50 per cent. Eastern Kentucky Scrgs.	
10. Steam pressure by gauge, lbs. per sq. in.	167·8
12. Temperature of steam leaving superheaters, deg. F.	441·9
13. Temperatures of feed water entering boiler, deg. F.	156·3
14. Temperature of escaping gases, deg. F.	496·6
15. Draft under damper, inches of water	173
16. Draft in furnaces, inches of water	·031
17. Air pressure at blower, inches of water	6·36
18. State of weather	
(b) Relative humidity, per cent.	·72
20. Total weight of coal, as received, pounds	958,074
21. Percentage of moisture	7·23
22. Total weight of coal, as fired, pounds	894,800
23. Percentage of moisture	·67
24. Total weight of dry coal, pounds	888,805
25. Slag, ash and refuse (dry Laboratory basis), per cent.	11·90
(A) Withdrawn from furnace bottom, pounds total	9,770
(B) Withdrawn from tubes, flues and combustion chamber, pounds total	9,862
(C) Blown away with gases, pounds (difference between Laboratory and actual weighed)	87,549
(D) Percentage of total lost with gases	82·8
(E) Percentage of combustible in slag and ash recovered, per cent. (combined analysis)	6·9
26. Total combustible burned, pounds	781,622
27. Total weight of water fed to boilers	8,249,536
28. Factor of evaporation	1·1473
29. Total equivalent evaporation from and at 212° F., pounds ...	9,464,693
32. (a) Equivalent evaporation per hour per boiler from and at 212° F., pounds	19,121
33. Equivalent evaporation per hour from and at 212° F., per sq. ft. of water heating surface, lbs.	4·09
36. Percentage of rated capacity developed	118·4
37. Water fed per pound of coal, as received, pounds	8·611
38. Water fed per pound of coal, as fired, pounds	9·219
39. Water evaporated per pound of coal dry, lbs	9·282
40. Water evaporated per pound of combustible, lbs.	10·554
41. Equivalent evaporation from and at 212° F., per pound of coal as received, pounds	9·879
42. Equivalent evaporation from and at 212° F., per pound of coal as fired, pounds	10·577

43. Equivalent evaporation from and at 212° F., per pound of coal dry, pounds	10.649
44. Equivalent evaporation from and at 212° F., per pound of combustible, pounds	12.109
45. Calorific value of 1 pound of dry coal by calorimeter, B.Th.U....	12,810
46. <i>Gross efficiency of boiler and furnace, per cent.</i>	80.67
47. Efficiency of furnace, per cent	99.79
49. Carbon dioxide, per cent. in flue gases	12.26
50. Oxygen, per cent.	6.82
51. Carbon monoxide, per cent. ....	.00
52. <i>Proximate analysis of coal:</i> —	

	As Received.	As Fired.	Dry.
(a) Moisture	7.23	.67	—
(b) Volatile	32.13	34.40	34.63
(c) Fixed Carbon	49.60	53.11	53.47
(d) Ash	11.04	11.82	11.90
	<hr/> 100.00	<hr/> 100.00	<hr/> 100.00
	<hr/>	<hr/>	<hr/>

Heat Balance.

	Method.			
	A.S.M.E.		Uehling.	
	B.Th.U.	Per Cent.	B.Th.U.	Per Cent.
(a) Heat absorbed by the boiler	10334	80.67	10334	80.67
(b) Loss due to evaporation of moisture in coal ...	8	.06	8	.06
(c) Loss due to heat carried away by steam formed by the burning of hydrogen,	486	3.79	463	3.61
(d) Loss due to heat carried away in dry flue gases	1527	11.93	1551	12.11
(e) Loss due to carbon monoxide	0	.00	0	.00
(f) Loss due to combustible in ash	23	.18	23	.18
(g) Loss due to heating moisture in air	39	.30	39	.30
(h) <i>Loss due to combustible carried away with flue gases, unconsumed hydrogen, hydrocarbons, radiation and unaccounted for.</i>	393	3.07	393	3.07
(i) Total calorific value of 1 lb. of dry coal ...	12810	—	12810	—
(j) Total per cent.	—	100.00	—	100.00

TEST ON FUEL PULVERISING EQUIPMENT ONEIDA STREET POWER PLANT.

December 11th—15th, 1919.

General Conditions—Average Temperatures, &c.

	No. 1	No. 2
1. Temperature of air entering dryer furnace, deg. F.	93.8	
2. Temperature of gases leaving dryer, deg. F.	181.8	
3. Humidity of outside air, per cent.	72.0	
4. Draft through dryer, inches of water .....	.77	
5. Vacuum in pulverisers, inches of water	5.0	5.16 avg. 5.08

Coal Temperatures, Moistures and Fineness.

6. Temperature of coal entering dryer, deg. F.	88·2
7. Temperature of coal leaving dryer, deg. F.	237·9
8. Temperature of coal leaving pulverisers, deg. F.	169·7
9. Moisture of coal entering dryer, per cent.	5·59
10. Moisture of coal leaving dryer, per cent.	1·61
11. Moisture of coal leaving pulverisers, per cent.	1·03
12. Fineness of pulverised coal, 200 mesh, per cent.	81·30
13. Fineness of pulverised coal, 100 mesh, per cent.	97·40
14. Fineness of pulverised coal 80 mesh, per cent.	99·30
15. Fineness of pulverised coal, 60 mesh, per cent.	100·00

Total and Hourly Quantities.

Crusher.

16. Total coal crushed, as received at crusher, tons	479·0
17. Coal crushed per hour, as received, tons	17·5

Dryer.

18. Total coal dried, as received at dryer, tons	471·2
19. Total coal dried per hour of dryer operation, as received, tons	6·7

Pulveriser.

20. Total coal pulverised, coal from dryer, tons	447·4
21. Capacity of pulveriser per hour, tons	5·0
22. Coal pulverised per hour, dry, tons, total	7·90
23. Coal pulverised per hour, dry, tons, per mill	3·95
24. Coal pulverised per hour, per mill, as received at plant, tons	4·23

Consumption of Lubricants.

24a. Total grease consumed by elevators and conveyors, pounds	6·0
25. Grease per ton of coal, as received, pounds	·012
26. Total grease consumed by pulverisers, pounds	13·0
27. Grease consumed per pulveriser per hour of operation, pounds	·112
28. Grease consumed per pulveriser per ton of coal pulverised, pounds	·028
29. Grease consumed on all equipment per ton of coal, as received, pounds	·040
30. Total oil consumed on all equipment, quarts	17·0
31. Oil consumed per ton of coal, as received, quarts	·036

Electric Energy and Coal Consumption.

32. Total energy consumed by crusher and green coal elevator	220·0
33. Energy per ton of coal, as received, K.W.H.	·47
34. Total energy consumed by dryer, K.W.H.	735
35. Energy per ton of coal, as received, consumed by dryer	1·53
36. Total energy consumed by pulverisers, K.W.H. (Fan and drive motor)	8,010
	Mill No. 1 Mill No. 2
37. Motor input per hour, H.P.	93·8 90·2
38. Energy consumed by pulveriser per ton of coal, as received, K.W.H.	16·72

39. Energy consumed by pulveriser per ton of coal, as pulverised, K.W.H.	17.90
40. Total energy consumed by pulverised coal conveyors, feeder blowers and feeders, K.W.H.	1.789
41. <i>Total energy consumed by pulverised coal conveyors, feeder blowers and feeders per ton of coal, as received, K.W.H.</i> ...	3.73
42. Total energy consumed by pulverised coal conveyors, feeder blowers and feeders per ton of coal, as fired, K.W.H.	4.00
43. Total energy consumed by all equipment on preparation and firing of pulverised fuel, K.W.H.	10.754
44. <i>Energy per ton of coal, as received, K.W.H.—Grand Total</i>	22.45
45. Coal equivalent for this energy at 1.5 lbs. coal per K.W.H. lbs.	33.68
46. Total coal used in dryer furnace	12.291
47. Coal per ton of fuel dried, pounds (based on coal as received) ...	25.66
48. Total coal and equivalent consumed in preparation and firing of one ton pulverised fuel, lbs.	59.34

Cost of Preparation—Operation and Maintenance.

49. Cost of labour per ton of coal—operation	\$0.143
50. Cost of fuel for drying, plus fuel for electric energy—Coal at \$4.00 per ton .....	.119
51. Cost of lubricants per ton of coal—Grease at 9c. per lb. ....	.007
52. Cost of labour per ton of coal—Maintenance .....	.036
53. Cost of material—Maintenance .....	.020
54. <i>Total cost per ton of coal</i> .....	.325

Note.—Item 49 is based on the labour required to pulverise coal sufficient for five boilers through a twenty-four hour run per day.

SUMMARY SHEET.

1. Energy consumed by conveyors, crushers, elevators, dryer, blowers and feeders, K.W.H.	5.73
2. Energy consumed by pulveriser, K.W.H.	16.72
3. Total energy, K.W.H.	22.45
4. Coal equivalent at 1.5 lbs. per K.W.H. lbs.	33.68
5. Coal consumed in dryer furnace, lbs. per ton of fuel dried	25.66
6. Total coal and equivalent, lbs.	59.34
7. <i>Gross efficiency less deductions for total coal and equivalent— Item 6</i>	78.36
8. Labour—Coal preparation	\$.143
9. Labour—Firing .....	.112
10. Labour—Ash removal .....	.025
11. Dryer fuel—Coal at \$4.00 per ton .....	.051
12. Electric energy—Coal per K.W.H. at 1.5 lbs. ....	.068
13. Maintenance (Labour at 3.6c.—Material at 20c. manufacturer's estimate—Lubricants at 7c.) .....	.063
14. Total cost of fuel preparation, firing, ash disposal and main- tenance .....	.462
15. Price of coal as purchased, per ton	4.000
16. Total cost	4.462
17. <i>Actual gross efficiency, per cent.</i>	80.67
18. <i>Net efficiency after all incidental costs have been accounted for, per cent.</i>	72.32

CONCLUSIONS

*Operating Costs for Pulverised Coal Plant and Mechanical Stokers
(per ton (2,000 lbs.) of coal handled).*

	<i>Pulv. Fuel System.</i>	<i>Modern Stoker Plant.</i>
Energy consumed to conveyors, crusher, elevators, dryers, fans and feeders, K.W.H.	5·73	Stokers and blowers, K.W.H. 10·94
Energy consumed by pulveriser, K.W.H.	16·72	—
Total energy, K.W.H.	22·45	10·94
Coal equivalent at 1·5 lbs. per K.W.H. lbs.	33·68	16·41
Coal consumed in dryer furnace, lbs.	25·66	—
Total coal and equivalent, lbs.	59·34	16·41
Labour—Coal preparation	\$0.143	—
Labour—Firing ....	.112	\$0.140
Labour—Ash removal (in plant) ....	.025	.064
Dryer fuel—Coal at \$4.00 per ton ....	.051	.000
Electric energy—Coal per K.W.H. at 1·5 lbs. ....	.068	.033

Maintenance.

Labour at \$.036—(Material at \$.020 manu- facturers' estimate — Lubricants at \$.007 ....	.063	Labour at \$.046. Material at \$.049
Total cost of fuel preparation, firing, ash disposal and maintenance ....	.462	Lubricants at \$.002. .007
Price of coal, as purchased per ton	4.000	.334
Total cost, per ton	4.462	4.000
Cost per ton of coal in P.F. System over modern stoker ....	.128	4.334
Actual gross efficiency, per cent.	80·67	—
<i>Net efficiency after all incidental costs have been accounted for, per cent.</i>	72·32	76·80
<i>Difference in favour of pulverised fuel system, per cent.</i>	1·44	70·88

EXCERPTS FROM FINAL NOTES.

By Mr. PAUL W. THOMPSON, on the PULVERISED FUEL APPLICATION AT THE ONEIDA STREET PLANT.

"In order to determine the feasibility of burning pulverised fuel, the Milwaukee Electric Railway and Light Company, early in 1918, decided upon a trial installation on one of the 468 H.P. boilers in the Oneida Street Power Plant.

"It is unnecessary to go into the details of the test or methods employed as these will be found in the final report of the test. It is sufficient to say that the test was properly conducted and particular care exercised in obtaining an accurate record of all quantities involved.

"Losses which are inherent in stoker practice, such as breakdowns in the stoker itself, breaking up clinkers, loosening clinkers, continually watching the fire to maintain correct and uniform thickness, watching the gas passes of the boiler to see that no large sparks which indicate a carrying away of combustible, dumping, and the many other operations that are necessary in stoker operation, are eliminated. In other words, efficient combustion is obtained at all times without continual supervision by an experienced operator, and from the standpoint of reliability of operation the odds are in favour of the pulverised fuel. This is an item for serious consideration in plants designed with 4·5 k.w. capacity or more per installed boiler horse-power, where the losing of a boiler due to stoker trouble at the time of maximum load on the station might seriously overload the remaining boilers or make it necessary to drop a portion of the load on the plant.

"A large portion of the ash resulting from combustion is carried on through the passes of the boiler and out of the stack. Owing to the fineness of this ash it apparently carried a considerable distance, even in a moderate wind before being precipitated.

"Strictly speaking, there is no such thing as a banked boiler when using pulverised fuel, as all that is necessary when it is desired to cut out a boiler is to shut off the coal feed and close all the dampers and auxiliary air inlets to the furnace. In this way the Milwaukee Electric Railway and Light Company have found by test that it is possible to hold the boiler up to pressure for about ten hours by the radiant heat stored up in the furnace and boiler setting which is gradually absorbed by the boiler.

"In a plant where the ratio of boiler hours to boiler steaming hours averages 43 per cent. or greater, which corresponds to an average daily plant load factor of 67 per cent., the saving resulting from the use of pulverised fuel is worth considering. Assuming 0·2 lb. coal consumed per B.H.P. banking hour in a plant equipped with underfed stokers, this loss amounts to about 1·5 per cent., which is a pulverised fuel burning plant should easily be reduced to one-half this figure, resulting in a net saving of 0·7 per cent. on this one item alone.

"The writer (Mr. Thompson) does not believe that under test conditions over a period of constant boiler rating the efficiency obtained with the use of pulverised fuel will exceed that which has been obtained from the best stoker practice under similar operating condition. However, under normal operation it is believed that the elimination of the many variable conditions entering into stoker operation will result in higher efficiency for the pulverised fuel installation. Overall efficiencies of boiler, furnace, and grate as high as 82 or 83 per cent. have been obtained on test with stoker-fired boilers, but normal operation day in and day out seldom exceed 76 per cent. in the very best practice where highly skilled help is employed in supervising the boiler room operation."

(3) RAILWAY LOCOMOTIVES.

TESTS MADE BY MR. J. G. ROBINSON ON THE GREAT CENTRAL RAILWAY.

An illustration, Fig. 19, of the locomotive as fitted up by Mr. Robinson for burning pulverised coal, has been taken from "The Engineer," April 25th, 1919, together with the following notes.

Missing Page

The engine used for these experiments "is of the 2—8—0 type, which was adopted by the Ministry of Munitions for service with the Forces in France, and of which a very large number have been sent overseas. It has two outside cylinders 21 in. diameter by 26 in. stroke, 56 in. coupled wheels, and a boiler barrel 15 ft. long by 5 ft. diameter, the firebox, which is of the flat-topped type, being 8 ft. 6 in. long outside. The engine is fitted with a Robinson superheater of twenty-two elements. When arranged for coal firing the grate area is 26 square feet. It will be seen that in order to make the firebox suitable for the use of pulverised fuel, the grate and ashpan were removed, and two openings, each 7½ in. diameter, were made through the water space of the back of the firebox, just above the foundation ring and clear of the cast iron footplate.

"The apparatus for injecting the fuel and primary air to the firebox is installed on the tender and is steam-driven throughout. The fuel is contained in a hopper, in the bottom of which are placed two horizontal conveyor screws, which are rotated through gearing by means of a small horizontal two-crank steam engine. This engine is connected to the feed screws by means of a two-speed train of spur gearing operating worms which drive worm-wheels on the feed-screw shafts. The object of the double gear is to ensure that the piston speed of the small engines shall be high enough to prevent undue cylinder condensation losses at the lowest rate of feed. On leaving the feed-screws the fuel is met by a blast of air at a pressure of about 14 in. of water, which is delivered through pipes by means of a fan driven at the speed of 2,500 revolutions per minute by a geared de Laval turbine. Steam for the engine driving the feed-screws is led from the boiler by means of a pipe and that for the turbine by similar connection, the exhausts from both being condensed in a series of pipes laid in the well of the tender tank, thus allowing a considerable portion of the heat of the exhaust of these auxiliaries to be returned to the boiler, which is fed by a pair of hot-water injectors capable of dealing with water at 140 deg. Fah. In case of any accident to the steam turbine or its steam connections, the fan is provided with a pair of clutches which enable the turbine to be disconnected, the fan being then driven by means of a chain by the engine operating the feed-screws. This provision enables the locomotive to continue at work in case of any such mishap."

Further tests and comparisons recorded by Mr. Robinson for hand-fired, pulverised coal fired and colloidal oil fired locomotives on freight service over a steep grade section of the Great Central Railway in the Peak district have been reviewed in the technical press, but whereas the fact has been established that locomotives so fired will accomplish approximately equal duty in equal time, no actual records as to cost or quantity of fuel used are as yet available for publication.

Possibilities in India and other Countries.

Colonel Bonner, late Locomotive Superintendent for the Great Indian Peninsula Railway, India, has conducted somewhat similar tests with an equipment of his own construction. It has been stated that the general use of pulverised coal on one of the railway systems in India would mean a saving in money in the neighbourhood of £1,000,000 per annum, and the release of some 75,000 rail truck journeys for other purposes.

These economies would embrace all incidental savings brought about by the use of coal fuel in place of locomotive coal now handled very considerable distances.

In India, and the same desire will be experienced in many other countries, it would be of great value to render serviceable for railway or general industrial uses the great variety of fuels which up to now have not received serious attention.

If the low-grade coal and lignite of the Khost, Dandote, Assam, Garo Hill and other districts can be used with equal success as has been achieved on the Lehigh Valley railway locomotive when burning Western American lignite then a new situation will be presented. The developments of these great deposits of fuel, of too inferior a grade to render mining operations or use on ordinary grates satisfactory, will become practicable.

In like manner experiments have been undertaken in Switzerland with an equipment designed by the engineering staff of the Swiss Federal Railways, and it is expected that a coal-pulverising plant will be installed in the near future, so that an adequate supply of suitable fuel will be available for the continuance of these trials, both with the original equipment and with apparatus of the standard American type.

The work that has been done in the States during the past 3 or 4 years in the application of pulverised coal to railway locomotives is perhaps one of the most encouraging features of recent developments. It was in locomotive boiler tubes and open hearth furnace regenerative chequers that the greatest difficulties occurred with regard to the deposit of ash slag.

By the removal of the ash trouble in locomotive fire boxes, boiler tubes and smoke boxes a most important advance has been made in the art of using coal in powdered form. It makes possible the firing of railway locomotives by this means and a realisation of the many economies following thereon.

So rapidly has this field been investigated that even after what may be called preliminary trials a considerable number of engines fired on this system were ordered by foreign Governments and railway companies.

Sweden was the country to take the lead in this direction. Sweden has no coal deposits but possesses large supplies of peat. In 1916 the Swedish State Railways Department experimented with powdered peat as a fuel for its locomotives and the directors recommended an appropriation of £72,917 (\$350,000) for the building of a factory to produce sufficient powdered peat to supply all the locomotives operating on one of its lines.

Many locomotives are now operating in that country on pulverised peat with which is mixed a small proportion of pulverised bituminous coal. (Some notes on this application are given in the "Railway Engineer," July, 1920.)

The next country to order locomotives for coal dust firing was *Brazil*. A start was made with 12 engines, and an order for further locomotives was to be given if the trials with the first 12 were successful. These proved to be so and the Brazilian authorities have now given instructions for the delivery of 20 more engines. The equipments used have been supplied by The Locomotive Pulverised Fuel Co., and the pulverising mills are of the Fuller type.

An article in the Railway Mechanical Engineer, Vol. 91, No. 11, gives a full description of the plant and engines, from which description the following notes have been extracted:—

"With about 500,000 square miles of territory containing deposits of coal which can be easily mined and transported to the

industrial centres, Brazil has been forced to import this material from Europe and America because of the fact that up to the present time it has been found impossible to burn the domestic coal successfully. In 1915 there were imported 1,346,147 metric tons, 561,150 of which came from America. The price of this coal has more than doubled on account of the war, the average price now paid being about £8 6s. 8d. (\$40) per ton. Even at this high rate Brazil has been unable to obtain more than 75 per cent. of its requirements.

"The difficulties encountered with the use of Brazilian coal are due to the large amount of sulphur and iron pyrites contained in it, which, combined with the ash, forms such a large amount of clinker that efficient combustion on ordinary grates is impossible. The analysis of the coal is as follows:—

Moisture	...	...	From 2 to 8 per cent.
Sulphur	...	...	3 to 9 "
Volatile	...	...	14 to 28 "
Fixed Carbon	...	...	34 to 58 "
Ash	...	...	26 to 30 "

"The relatively high volatile and carbon content make it very desirable for fuel if it can be burned successfully.

"As a result of investigations the Central Railway of Brazil decided to instal a pulverised fuel-preparing plant, having a capacity of 15 tons per hour, to be used for steam locomotives and stationary boiler equipment at shops located at Barra do Pirahy, which is about 65 miles north of Rio de Janeiro. An order was placed for 12 ten-wheel passenger locomotives to be equipped with pulverised fuel-burning apparatus.

"The ground was broken for the pulverising plant May 17th, 1917, and the plant was placed in operation August 22nd. The first locomotive fired with pulverised fuel was put into service August 27th, and the rest of the locomotives were put into commission at the rate of one a day thereafter. On September 9th the first run was made with the pulverised national coal.

"With the successful use of native coal, Brazil has solved one of its most perplexing economic problems. The Brazilian Government has contracted to equip 250 of the locomotives on the Central of Brazil with the pulverised fuel-burning equipment during the next five years. This contract also includes the equipping of stationary boilers and industrial furnaces.

"The 12 locomotives which were built in America and sent to Brazil equipped to burn powdered fuel weigh 172,000 lb., and have a maximum tractive effort of 28,300 lb. They have a gauge of 5 ft. 3 in., cylinders 21½ in. by 28 in., driving wheels 68 in. and weigh 122,000 lb. on drivers. They are equipped with firebrick arches and superheaters, have a total heating surface of 2,149 sq. ft. and a superheater heating surface of 428.2 sq. ft."

Italy and France are now on the point of adopting pulverised coal for locomotives, and the *Australian Government* have fully investigated American practice with a view to converting some of their engines at an early date.

Unfortunately, the American experimental locomotives that had been running for a year or so on pulverised coal were requisitioned by the Government at the entry of America into the war. It was then essential

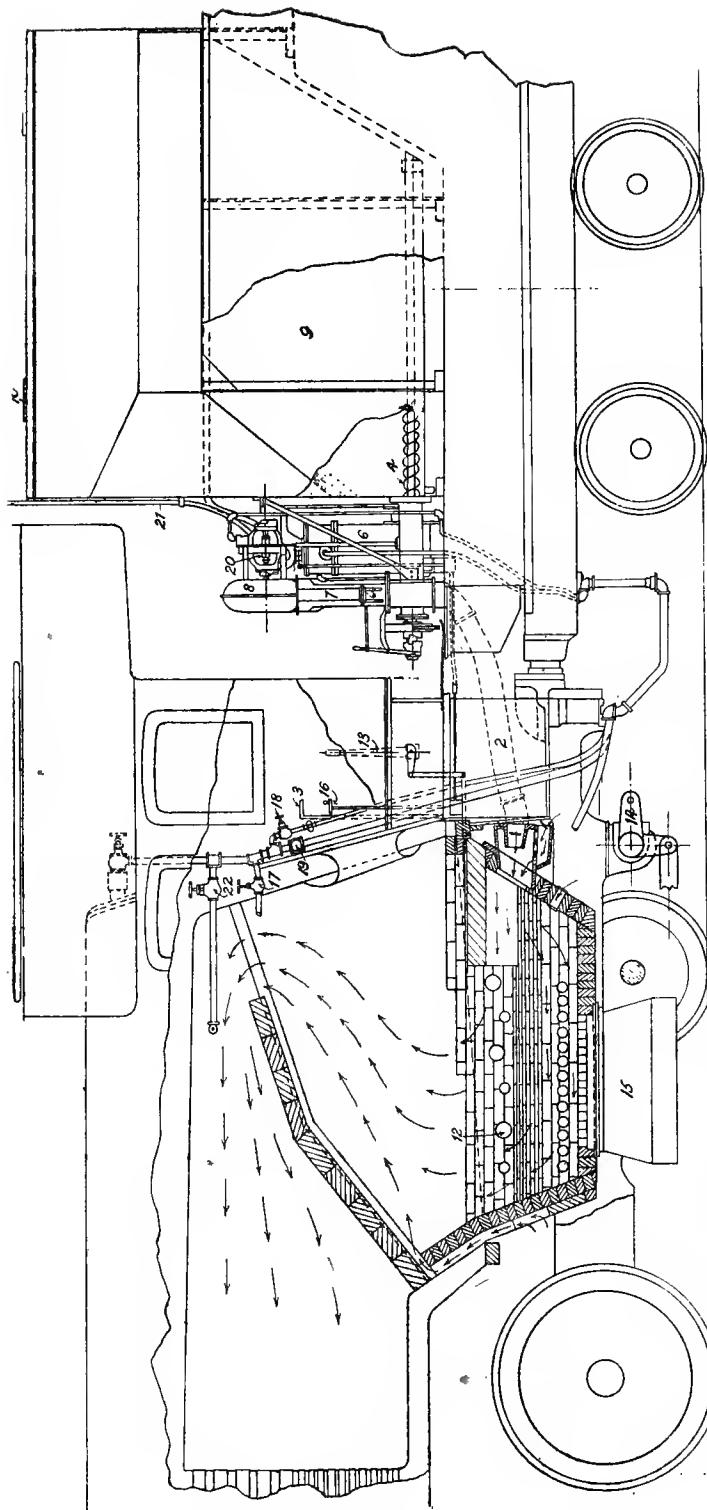


FIG. 20.—“FULLER” LOCOMOTIVE APPARATUS FOR POWDERED COAL.

Mark No.	Description.	Mark No.	Description.
1.	Burner.	12.	Side Air Ports.
2.	Coal and Air Conveying Pipe.	13.	Side Air Port Control Lever.
3.	Control Lever for Natural Draught Butterfly Valve.	14.	Slag Pan Dumping Lever.
4.	4" Feeder Screw.	15.	Slag Pan.
5.	4" Quadruple Coal Dust Feeder.	16.	Coal Feed Control Wheel.
6.	3½" X 2½" Two Cylinder Feeder Engine.	17.	Stack Draught Blower Control Valve.
7.	Blower Connecting Pipe.	18.	Control Valve for Turbo Fan.
8.	Fan Casing.	19.	Control Valve for Coal Feeder Engine.
9.	Tank for Pulv. Coal. Capacity 3 tons.	20.	Steam Turbine Blower.
10.	Filling Hole.	21.	Blower Turbine Exhaust.
11.	Gear and Clutch (700% Overall Variation).	22.	Round House Steam Connection for starting up from cold.

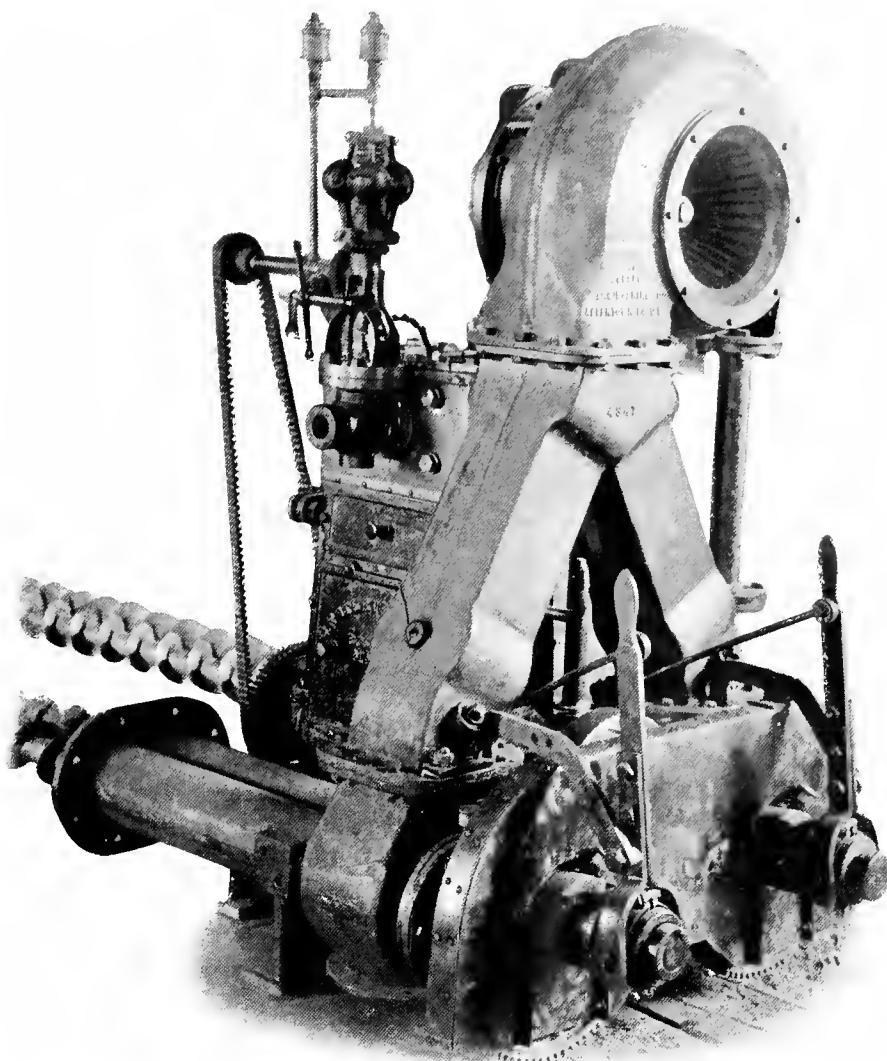


FIG. 21.—FULLER LOCOMOTIVE EQUIPMENT—SHOWING PULVERISED COAL TWIN FEED SCREWS, CHANGE SPEED GEAR LEVERS, VERTICAL STEAM ENGINE AND STEAM TURBO AIR BLOWER.

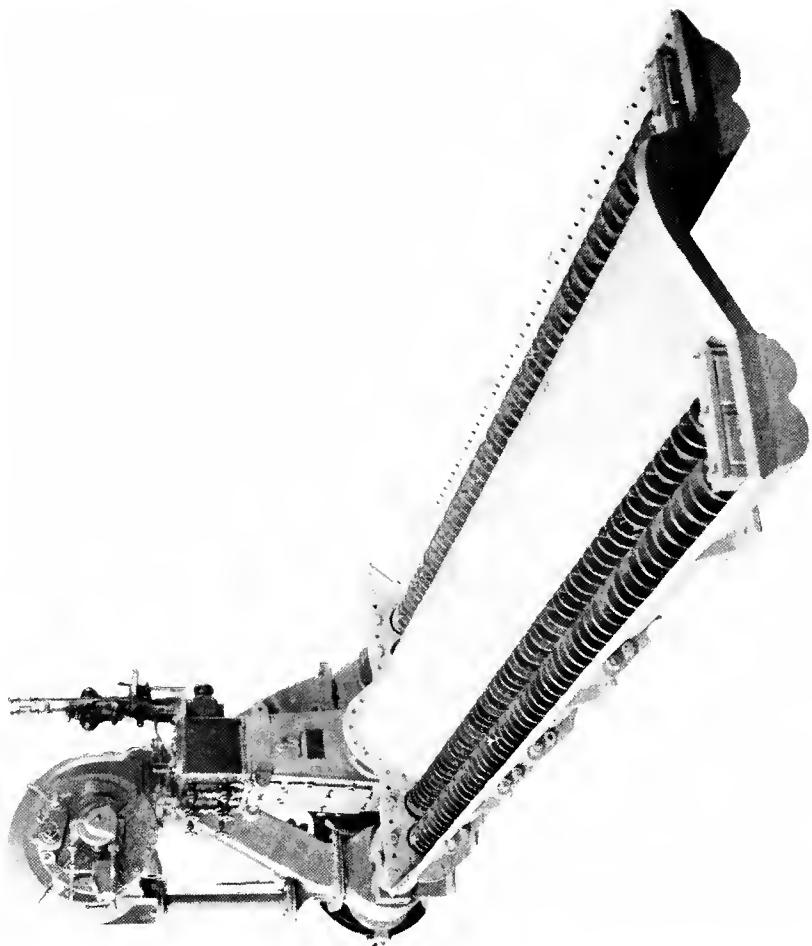


FIG. 22.—ASSEMBLY OF FULLER LOCOMOTIVE EQUIPMENT, TYPE A, SECTION SHOWING COMPLETE BASE FOR PULVERISED COAL TANK, THE SIDES OF WHICH ARE BOLTED TO THIS CAST IRON BOTTOM SECTION.

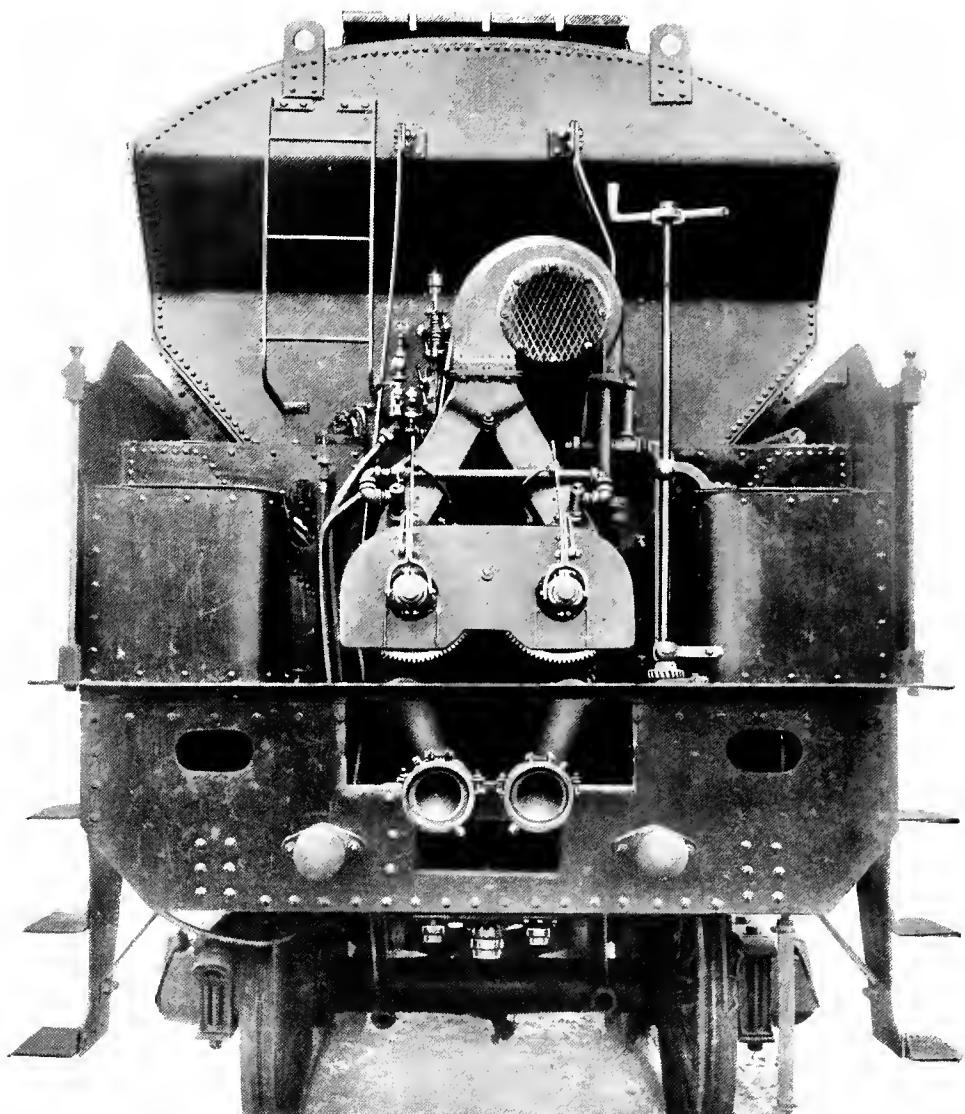


FIG. 23.—FRONT VIEW OF TENDER (ITALIAN STATE RAILWAY LOCOMOTIVE) SHOWING PULVERISED COAL CONTROL EQUIPMENT IN POSITION.



FIG. 24.—LOCOMOTIVE 1360 PULLING A 38 CAR TRAIN, 982 TONS (82 TONS ABOVE RATING) UP A 0 58% GRADE.
APRIL 7TH, 1920. SPEED 20 MILES PER HOUR. WESTBOUND.

to discontinue the use of experimental engines and make every locomotive available for hauling freight trains throughout the country. This meant that all engines must be suitable for working on any part of the railway system, it being inadvisable to hold engines for restricted duty near the pulverised coal supply depots. Progress with the systems then under test was therefore discontinued and all the test engines were reconverted to hand or mechanical firing so that they could then be used in any locality.

To the writer's knowledge there are now only two engines operated on pulverised fuel in America—the heavy freight locomotive on the Lehigh Valley Railroad and the small switch engine which has been running for some two years on numerous classes of fuel at the works of the Fuller Engine Co. at Allentown.

RECENT DATA AND PROGRESS

The following notes have been taken from a paper which appeared in "The Railway Engineer," July, 1920.

Lehigh Valley Railway Results.

Fig. 24 shows a pulverised coal fired locomotive on this line hauling a 38-car freight train, 982 tons, or 82 tons above rating, up a 0·58 per cent. grade, speed 20 m.p.h. Fig. 21 shows the tender equipment used. The Lehigh Valley locomotive is run on a mixture of 55 per cent. raw anthracite silt and 45 per cent. bituminous coal. Full steam pressure is maintained easily at all times, and the anthracite silt contains 38·42 per cent. of ash, and has a B.Th.U. value of 9,675, while the soft coal which is mixed with this has an ash content of 11·6 per cent. and a B.Th.U. value of 12,650. Analyses of these coals are as follows:—

<i>Anthracite Silt.</i>		<i>Soft Coal.</i>		
	Per cent.		Per cent.	
Moisture	2·26	Moisture 	1·9
Volatile	10·39	Volatile 	36·59
F.C.	49·30	F.C. 	49·89
Ash	38·42	Ash 	11·6

On this line the locomotive operating between Easton and Pemberton makes a daily round trip of 87·4 miles (43·7 miles out and return).

The fuel mixture (55 per cent. anthracite, 45 per cent. bituminous coal) gives an evaporation of between 8·07 and 9·34 lb. of water f. and a., representing a consumption of between 8 and 11 tons of coal per trip. Original test figures are given later for coal mixture of 25 per cent. anthracite, 75 per cent. bituminous. The mixture now being used is 58½ per cent. anthracite, 41½ per cent. bituminous, which shows that at least a 50-50 mixture can be used with every degree of success.

As to cost of fuel and cost of preparation, anthracite is delivered at \$1.43 per ton and soft coal at \$4.23 per ton, and the overall charge for preparation of the pulverised fuel is 40c. per ton on a basis of 1,000 tons per day. On this daily consumption it has been calculated that the nett saving is \$1,325.00 per day, or \$483,625.00 per annum in favour of pulverised coal firing, apart from labour saving and other incidental economic features.

The maximum rated tonnage of this locomotive, hand-fired, west-bound over the division, is 900 tons, while the trains hauled by the pulverised coal-fired locomotive have averaged from 900 to 1,080 tons.

Specifications of the Lehigh Valley locomotives are as follows:—

Class	...	...	...	10 wheel, 4—6—0.
Cylinders	...	...	...	20 in. by 26 in.
Steam pressure	...	...	...	175 lb.
Drivers	...	...	...	63 in. diam.
Heating surface	...	...	...	1901·5 sq. ft.
Exhaust nozzles orig.	...	...	...	3½ in. (twin nozzles) now 3½ in. each.

(In other words, the tips have been entirely removed, and there is a free open exhaust from the cylinders which greatly reduces back pressure and makes a saving in power.)

Weight on drivers	...	...	123,900 lbs.
Total weight	...	...	157,675 lbs.
Coal capacity	...	...	12 tons.
Water capacity	...	...	7,000 gallons.
Tractive power	...	...	22,700 lbs.

Report of test Locomotive No. 1360. Lehigh Valley R.R.
Class of service, freight—between Easton and Packerton—
43·7 miles.

Type of locomotive, 10 wheel. J-49. Tractive power, 22,700.
Rated freight train tonnage, 900 (Western Trip), 2,250 (Eastern trip).

Lehigh Valley Locomotive Tests.

Run No. : Date, October :	19 23	20 27	21 28	22 28	23 30	24 30	25 31	
Direction	...	West	East	West	East	West	East	West
No. of cars	...	{ 10 41 }	5	43	32	36	47	40
Tons	...	1,537	—	{ 1,029 710 }	{ 1,957	797	2,509	928
		m. s.	m. s.	m. s.	m. s.	m. s.	m. s.	m. s.
Running time	...	2 50	—	3 05	—	3 05	3 15	—
Delayed time	...	4 05	—	2 38	—	0 27	2 20	—
Total Time	...	6 55	—	5 43	4 26	3 32	5 25	4 25
Speed m.p.h. (Western trip haulage against incline)	...	14·6	—	14·5	—	14·5	—	—
Coal used (lbs.)	...	13,975	6,642	14,939	6,516	12,802	13,244	—
Water used (lbs.)	...	87,500	51,200	89,000	55,300	79,200	87,200	—
Evap. actual	...	6·26	7·74	5·96	8·5	6·18	6·58	—

Notes.

Run No. 19.—10 cars Easton to East Penn Junction, 41 cars East Penn to Packerton.

Run No. 20.—Local freight, making all stops.

Run No. 21.—“Pick up”; 710 tons from Easton; 1,029 tons from East Penn; 925 tons from Laurys to Packerton.

Run No. 22.—Light to East Penn; 1,957 from East Penn.

Run No. 25.—Revolution counter not operating; no record of coal consumption.

Coal used on all above trips a mixture: (25 per cent. anthracite silt, Penn; 75 per cent. bituminous, W. Va.).

	<i>Harrison Mine, Clarksburg, W. Va.</i>	<i>Packer No. 5 Colliery Lehigh Valley Coal Co. (Bituminous).</i>	<i>Per cent. B.Th.U.</i>	<i>Per cent. B.Th.U.</i>
Moisture	...	0·70	5·35	
Volatile	...	36·45	8·86	
Fixed carbon	...	54·95	13,175	59·40 10,480
Ash	...	7·90	31·74	
Sulphur	...	2·44	—	

Developments in Italy and Holland.

Due to the scarcity of fuel in Italy at the present time, a situation which is becoming more critical every day, the Italian State Railways decided in December to equip two of their new heavy consolidation type locomotives for burning pulverised coal, the object being to utilise the vast fields of Italian lignite as railway fuel.

Little alteration was found necessary in the locomotive proper, the only change of importance being in connection with the tender design, a U-shaped tank being substituted for the former type constructed for lump coal, and also to move the tank bodily on the tender 7 in. toward the rear in order the better to distribute the weight on the front and rear axles. In view of the fact that only one coal-pulverising plant is to be erected in the first instance, it was considered advisable to provide for a much larger fuel capacity on the tender than would otherwise be required, and a coal tank holding 10 metric tons instead of 6 metric tons has therefore been provided.

The raw coal which will be burned on these locomotives has the following analysis. Figures representing the limits in each case are given:—

	<i>Per cent.</i>
Moisture	12·52 to 26·80
Ash	11·6 to 32·6
Volatile	31·5 to 60·94
Carbon	35·26 to 68·50
B.Th.U. values from	3,640 to 10,440

The average analysis of Italian lignite to be tested on the locomotives contains approximately:—

Ash	...	...	...	10 per cent.
Volatile	...	...	...	40 "
F.C.	...	...	...	30 "
Moisture	...	...	...	20 "

There are so many lignite mines in Italy in different localities that it is very important to utilise this fuel as far as possible in place of costly imported coal.

A similar plant and locomotive equipment for identical types of railway engines are to be started up on the Netherlands State Railway system shortly.

Pulverised Peat-Fired Locomotives in Sweden.

As to the operation of railway locomotives by pulverised peat, an excellent article by Bureau Engineer, Carl Flodin (Centraltryckeriet, publishers, Stockholm, 1916), includes full data regarding tests made with

peat-fired eight-coupled freight locomotives: tractive power, 9,000 kg.; weight, 51,000 kg.; tender, 36,000 kg.; water capacity of tender, 14,000 kg.; pulverised peat, 4,000 kg.

Tests were carried out in November, 1915, and it was then found that, for equal boiler duty 1 kg. of coal was equal to 1·45 kg. of pulverised peat, the coal used having a calorific value of 7,240 cals. and the peat as used 4,400 cals., or approximately 13,000 and 7,900 B.Th.U. per lb.

The arrangement of the firebox setting allowed for a small grate on which coal was burnt under the incoming mixture of powdered peat and air. On this small hand-fired grate 3 to 4 kgs. of coal were consumed per 100 kgs. of peat, the analysis of peat and coal was as follows:—

	<i>Powdered Peat.</i>			<i>Coal.</i>	
	<i>Per cent.</i>			<i>Per cent.</i>	
Carbon	47·0	73·5
Hydrogen	4·5	4·4
Oxygen	29·5	8·6
Sulphur	0·5	1·5
Nitrogen	1·1	1·2
Ash	3·2	6·2
Moisture	14·2	4·6
	<hr/>			100·0	<hr/>
	<hr/>			100·0	<hr/>

Analogous tests made with coal-fired and powdered peat-fired locomotives gave the following overall boiler efficiencies and firebox temperature of gases:—

	<i>Efficiency.</i>		<i>Temperature.</i>
	<i>Per cent.</i>		
Hand coal-fired ...	65		1,510° F.
Pulverised peat-fired ...	73		1,670° F.

Recorded and corrected figures for parallel trips with coal and peat-fired locomotives are given by this writer in his paper; the more important of these figures have been extracted and tabulated hereunder:—

Results obtained on Coal (Hand-Fired) and Pulverised Peat-Fired Locomotives on the Swedish Government Railways.

Parallel Test Run.	Trip Number.	Weight of Loco., Tender and Wagons.	Wagons.	Average Speed, Km/Hr	Consumption in Kg. of Fuel per 1000 metric tons per Km. 1000 Kg. Inclusive Loco. and Tender.	Smoke-box Temp.	Kg. Steam per Kg Fuel.
A. Freight service.	1. Pulverised peat	Ton/1000 Kg.	Ton/1000 Kg.	29·2	37·5	255	4·69
	2. Coal ...	787	700	27·5	25·6	290	6·83
B. Freight service.	3. Coal ...	782	700	28·7	27·7	312	6·55
	4. Pulverised peat	787	700	27·0	40·7	294	4·77
C. Passenger service.	5. Pulverised peat	387	300	42·3	56·9	289	4·67
	6. Coal ...	382	300	41·7	39·0	263	7·05

With the 4,000 kg. of peat fuel taken on board, the locomotive pulling a 650-ton freight train or a 300-ton passenger train, it was found that these quantities of fuel on the section of line in question, and at the average train speed mentioned, would be sufficient respectively for a 100 and 130-km. run.

The first State peat-dust factory for the supply of fuel to locomotives was started up last year (1919). This factory has a capacity of 20,000 tons of peat powder per annum. In the preparation of the peat, which is delivered to the works in semi-dry state containing 25 per cent. to 40 per cent. of moisture, the fuel is first dried to 12 to 16 per cent. of moisture, below which point it is not reduced. The pulverised peat passes a screen having 100 meshes per sq. cm., and is made from the fines extracted from the bulk. Coarse fibrous material, 3 to 8 per cent. of the bulk, is removed by sifting and is not pulverised, this portion of the peat being used for textile work in the making of a wool-like fabric.

From 3 tons of air-dried turf, 2 tons of peat powder are obtained. The latter contains 12 to 16 per cent. of moisture, is non-explosive and non-hygroscopic. It can be stored for long periods without fear of spontaneous combustion, the only effect of the high percentage of moisture being the necessity of employing a small hand-fired coal grate to ensure continuous ignition of the fuel and evaporation of the moisture.

The International Railway Fuel Association, which holds annual conventions in Chicago, appointed in 1914 a committee to investigate the question of utilising pulverised coal, more especially with regard to its application as a locomotive fuel. The reports submitted to the Conventions of 1915-1916 and 1917 contain invaluable records of the progress made in the use of pulverised coal for this purpose. Very full discussions took place at these meetings and the views of many leading railway men and engineers are fully reviewed. It was stated that:—

“The cost of fuel for the 65,000 steam locomotives in use in the United States will approximate from £52,083,333 (\$250,000,000) to £57,291,666 (\$275,000,000) per annum, and now represents about 25 per cent. of the total transportation account expenses.”

Of this amount of fuel from 20 per cent. to 40 per cent. could have been saved if powdered coal had been used.

The stated advantages to be gained from the use of pulverised coal on locomotives are reproduced in this report *in extenso* on pp. 45 to 48, because most of the points made will equally apply to railway operation in this country and throughout the Empire.

At the 1916 Convention of this Association the results of the previous twelve months were reported; many interesting facts are recorded in the transactions for that year. The following tables set out some of the fuels used.

“Fuels that have been Burned in Pulverised Form.

“During the past year various fuels have been successfully burned in pulverised form in railway locomotive and stationary boilers performing regular service.

“The analyses are of the fuels when in pulverised form, ready for use.”

CHICAGO AND NORTH-WESTERN RAILWAY.

Contents.	Illinois Bituminous.	Kentucky Bituminous.	North Dakota Lignite.
	Unwashed Screenings.		
Moisture	3·18% to 15·36%	1·9% to 2·8%	1·8%
Volatile	Average 34%	36·0%	47·25%
Fixed Carbon	Average 47%	54·0%	40·91%
Ash	Average 10%	8·0%	9·32%
Sulphur	Average 1·70%	0·79%	0·72%
B.Th.U.	10,720 to 12,400	13,964	10,960
Fineness—			
Through 100 Mesh ...	90·7% to 99·69%	93·0%	98·0%
Through 200 Mesh ...	71·45% to 97·06%	83·0%	95·9%

NEW YORK CENTRAL RAILROAD.

Contents.	Pennsylvania Bituminous. Run of Mine.	Brazil, South America, Bituminous. Run of Mine.
Moisture	% % % % % 0·72 0·95 0·51 0·88 0·67	% % % 7·90 9·15 1·73
Volatile Carbon	28·75 30·85 31·25 35·67 21·63	28·04 29·42 9·50
Fixed Carbon	62·51 59·80 59·17 63·05 65·16	34·73 38·29 60·50
Ash	8·94 9·35 9·59 10·40 13·21	29·33 23·14 28·27
Sulphur	2·49 2·30 2·21 1·64 1·51	3·16 2·61 9·1
B.Th.U.	14,096 13,773 13,804 13,912 13,671	8,820 10,080 10,177
Fineness—		% % %
Through 100 Mesh ...	From 88·0% to 96·5%	99·8 99·8 99·8
Through 200 Mesh ...	From 66·5% to 96·6%	96·6 96·6 96·6

THE DELAWARE AND HUDSON COMPANY.

Contents.	Pennsylvania Anthracite. Waste Trailings from Culm Banks.	Pennsylvania Bitumen. Run of Mine.
Moisture	Average 0·50%	Average 0·50%
Volatile Carbon	" 8·30%"	" 33·0%
Fixed Carbon	" 72·09%"	" 57·50%
Ash	" (12% to 22%) 16·50%"	" 9·0%
Sulphur	Average (0·66% to 1·97%) 1·00%	Average 2·0%
B.Th.U.	" 12,000	" 13,750
Fineness—		
Through 100 mesh ...	98·7% 100·0% 99·68%	98·1% 100·0% 98·46%
" 200 " ...	75·3% 85·6% 92·41%	77·0% 86·5% 89·37%

The benefits to be derived from the use of powdered coal are stated by this Committee to be:—

“(1) *Sustained Boiler Horse Power.*—With powdered coal the tendency toward the more uniform, intense and sustained fire box temperature, as well as the automatic, continuous stoking of the fuel and the burning of the same in suspension; feeding of practically dry fuel to the furnace; reduction in the clogging and leakage of flues and the reduction in the various heat losses, should all tend to maintain the boiler capacity at its maximum effectiveness under varying conditions.”

“(2) *Ability to run Locomotive for relatively long continuous mileages or periods.*—The length of continuous runs for road or yard steam locomotives is limited to from 100 to 200 miles by the accumulation of clinker on the rocking and dead grates, which necessitates ashpit facilities and labour for removing.”

“As locomotives burning oil are being regularly and successfully operated on runs from 300 to 450 miles each way, the same should be entirely feasible when burning powdered coal.”

“(3) *The Firing of the Boiler entirely automatic.*—No fuel whatsoever supplied to the furnace by hand shovelling. The burning of coal on grates requires the skilful distribution of the fuel to the exact points where needed over the grate area, in order to avoid the liability of holes in the fire, or to prevent waste of fuel through banking and clinkering, with consequent steam failure. With powdered coal there is no hand firing whatever, all fuel being supplied automatically by mechanical means.”

(4) *No Cinders, Sparks or Smoke.*—After reviewing previous devices for the reduction of engine smoke, this report goes on to say that:—“This method, therefore, seems to be the logical solution of the question at engine houses, terminals and on the road, and the one that should greatly reduce the loss of heat and fuel cost resulting from imperfect combustion in existing and future locomotives. Moreover this method of combustion should avoid the necessity for the removal of engine houses, yards and terminals outside the smoke and cinder restrictive areas of large cities at enormous expense and inconvenience, as has been considered, for example, by the City of Chicago.”

“(5) *Material Reduction in Cylinder Back Pressure* through greatly enlarged exhaust passages. The elimination of ash pans, grates, smokebox diaphragm, baffles and nettings substantially reduces the retardation of the products of combustion through the boiler. This in combination with the means employed for producing combustion with powdered coal, enables the use of exhaust passages enlarged from 100 to 200 per cent. in area, as compared with those required for burning coal on grates. The enlargement of the exhaust passages will greatly reduce the cylinder back pressure losses, which under certain speed conditions frequently equal as much as 25 per cent. of the engine power developed.”

“(6) Saving in Inspection, Maintenance and Operation through the Complete Elimination of Grates, Ash Pans, Dampers and Operating Gear, Smoke Box Diaphragms, Baffles, Nettings, Spark Hoppers and Hand Hole Plate, Coal Pushers, Firing Tools, Squirt Hose and like equipment.”

“(7) Enclosed Fuel Container Prevents the Spilling and Loss of Coal, and its being subjected to Snow, Rain or other unfavourable conditions.”

“The general practice with all solid fuel is to use it in the locomotive in its raw state as furnished from the mines. For example, run-of-mine bituminous coal from a wet mine is usually loaded into an open car where it may take on additional moisture from the rain and snow, then dumped into a wet pit, conveyed into an open storage bin and finally dumped into an open tender. The result is that the coal when fed into the furnace is frequently in the nature of a slushy mixture of coarse and fine coal, which must be dried out by absorption of heat . . . before it can become usable in generation of steam.”

“With powdered coal the fuel is supplied to an enclosed airtight container on the tender (suitable for either powdered or liquid fuel), prepared to uniform fineness and thoroughly dried, so that when fed to the furnace it immediately produces effective heat.”

“Furthermore the coal is not touched by hand or shovel from mine car to furnace and there is no loss by pilfering, dropping from tender container, gangways, through holes in deck, or by firemen shovelling undesirable fuel off the tender on right-of-way.”

“(8) More uniform Furnace Temperature, reducing the liability of Fire Box and Flue Leakage.”

“(9) No Special Fuel required for firing up.”

“(10) Ability to make use of Inferior Qualities and Grades of Solid Fuel.”

“(11) Reduction of Heat Losses from Combustion.—Locomotive boiler losses (the percentage of loss increasing with the rate of firing, the character of induced draught and the reduction in the relative grate area) are largely contributed to by the heat produced by combustion that is carried out by the smoke stack, by excess of air entering through the grates and fire doors; loss by unconsumed coal that is carried out of the smoke stack in the shape of cinders and sparks; stand-by losses such as firing up, drifting, stoppage at the termination of the trip or day's work; radiation; vaporising moisture in coal; unconsumed carbon and ash and smoke. Taking into consideration the effect of burning powdered coal in suspension on the various heat losses enumerated, it is most conservative to place the saving to be effected at 25 per cent. of the coal fired, actual performance to date having shown as high as 30 to 40 per cent. saving.”

“(12) No liability to Set Out Fires.”

"(13) Reduction of delay for Building, Cleaning or Dumping. Fires at Terminals and Cleaning Flues and Smoke Boxes.—The time required to perform this work on steam locomotives represents a large percentage of the maximum non-productive delay to power, and is directly responsible for much road and yard crew and shop expense."

"With powdered coal there are no grate fires to clean; the extremely fine nature of the ash and absence of cinders result in practically no accumulation in the flues or smoke box."

"(14) Elimination of Ash Pit Tracks and Ash Handling Facilities at Terminals and Intermediate Stations.—The only non-combustible residual matter to be disposed of from the powdered coal furnace is a slag which is of a glassy nature and composed principally of silica, iron and aluminium. This being of a brittle and easily removable nature when solidified, can be readily removed without the usual labour, ash pit track, grate and ash pan cleaning and clinkering and ash handling facilities and equipment. When fuel is low in ash, and particularly in iron, sulphur and aluminium, the amount of slag produced is almost negligible."

"(15) No Clogging or Cutting Out of Superheated Units and Boiler Flues. As the proper burning of powdered coal produces no cinders and as the ash is of the nature of an impalpable powder, scouring in tendency, there is no clogging of the superheater or boiler flues, and the accumulation of ash is practically nil."

"(16) Reduction of Poisonous Gases through the Smoke Stack."

"(17) No Cinders or Ashes to Destroy Ballast or Wooden Cross Ties or Trestles."

"(18) Less Educational and Physical Requirements of Labour for Firing."

That this question of using coal in pulverised form has assumed an ever growing degree of importance is further indicated by the remarks made by The International Railway Fuel Association Committee in their 1917 proceedings, in the volume for that year will be found the following comments:—

"The railways within the United States for the current year are being called upon to pay from 40 to 100 per cent. more for fuel than heretofore, when the cost of locomotive fuel alone amounted to approximately £62,500,000 (\$300,000,000) per annum—next to labour, the largest single item of cost for conducting transportation."

"The average mechanical delay on one of the largest running repair stations is from 10 to 11 hours, and the lowest delay at its despatching stations is from 3½ to 5 hours, with an average of something over 6 hours for all stations. There is no question but that the elimination of the existing ash pit delays by the use of pulverised fuel would reduce the terminal delays to one-half of what it is at the present time, and this opportunity for relieving the yard congestion would seem to be the most efficient and economical means for increasing the net earning capacity of the railroads."

"With regard to the rapidity with which locomotives can be brought up to steaming pressure when fitted with powdered coal burners, figures representing the average of a large number of actual observations were recorded; these figures show the following results:—

Mixture.

Approximately 60 per cent. anthracite and 40 per cent. bituminous.

Initial Temp. of Water in Boiler.	Time to Raise to 150 lbs. Steam.
70 degrees	... ... ... 52 minutes.
100 degrees	... ... ... 44 minutes.
200 degrees	... ... ... 35 minutes."

From the foregoing notes and extracts from the proceedings of American Institutions it will be seen that considerable attention has been and is still being directed towards the equipment of heavy freight and passenger locomotives with pulverised fuel burning apparatus.

In the Railway Age Gazette, Vol. 62, No. 24, attention is also called to the fact that only about two-thirds of the total fuel purchased for locomotive operation is actually utilised while hauling trains, the remaining one-third going into the so-called "stand-by" loss, including the cleaning, building and maintaining of fires on grates during the period the engine is standing or otherwise not utilising steam for locomotion, either light or with train.

MARINE PROPULSION.

In the direction of practical application of pulverised coal for marine boilers comparatively little further progress has, as yet been made, but the interest shown by some of the leading shipping companies in Europe during the past two years 1919-20 suggests that the use of pulverised coal for firing boilers on board ship is quite likely to be adopted under certain circumstances in the near future. Developments in this direction must of necessity be slow, and the general use of powdered coal on board ship, if this should ever result, will not take place until some further improvements have been made, and, it is hoped, altogether novel and more efficient methods of pulverisation on board, have been successfully evolved.

Once it becomes possible to substitute powdered coal firing for hand firing the appalling conditions which so frequently exist in the stokehole, more especially in tropical climates, will for ever be removed.

In this connection, it was reported that in 1915 the Pacific Coast Steamship Co., of Seattle, Washington, operating passenger and freight steamers between San Francisco and Puget Sound ports, etc., intended to charter a tug to be fitted up for burning pulverised coal. Although no information has been sought as to the results of these experiments, no actual progress in this direction appears to have been made public.

The most important application of which the writer has been informed was made during the war period to one of the boilers of H.M.A.S. "Skylark" by Engineer Commander Brand, who ran his pulverised coal fired boiler all through the war years on pulverised coal taken on board and stored in closed bunkers.

To face page 83.

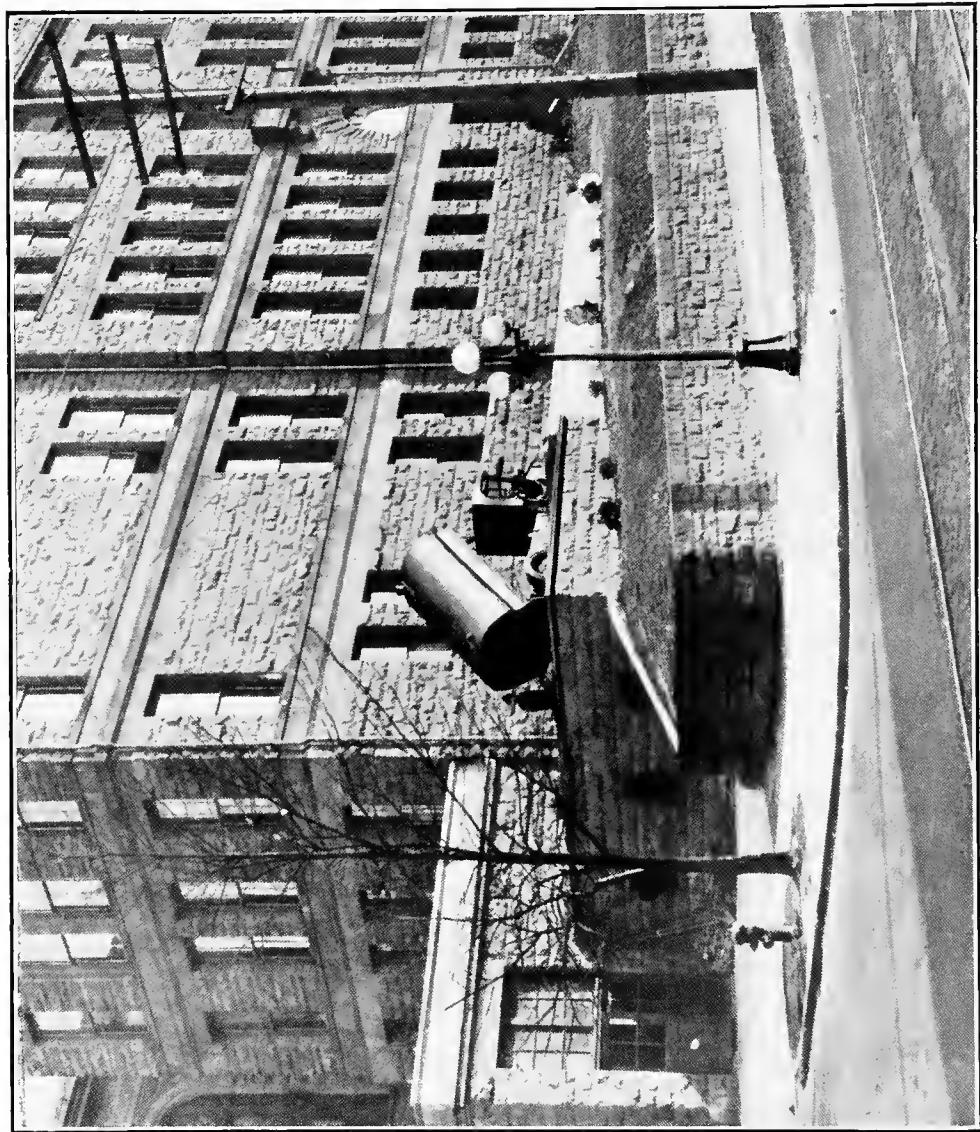


FIG. 25.—TYPE OF DELIVERY TRUCK USED AT SEATTLE FOR DISTRIBUTION OF PULVERISED COAL TO CONSUMERS.

There are some vital questions to be solved before pulverised coal can be successfully used as a marine fuel, to which both full consideration and actual trial must be given in order to determine the most advantageous method to be adopted for passenger, cargo, naval ships, tug boats or river craft. Some of these various considerations are:—

- (a) Whether the pulverised coal to be used can be shipped in bulk, and kept without danger for the period of the voyage.
- (b) Whether complete equipment including dryers and pulverisers should be installed so as to use any coal at any port.
- (c) Whether previously dried coal should be bunkered and pulveriser mills only installed on board ship.
- (d) Whether the self-contained unit pulveriser and burner either with or without dryer would be preferable.

Here again, in the opinion of the writer, the Trent or other such system of fuel treatment may be a means of providing certain quantities of pulverised fuel, which would be eminently suitable as marine fuel.

Upon all these and, no doubt, many other details or difficulties not as yet foreseen it remains for the future to find a solution.

DOMESTIC AND OFFICE BUILDINGS, CENTRAL HEATING.

SMALL CONSUMERS.

It may well be within the bounds of successful commercial enterprise for central pulverised coal companies to deliver powdered coal daily to small consumers. The economies to be gained when burning powdered coal in small quantities are as important, in the aggregate, as the savings to be effected in large works. The small consumer cannot always put down a pulverising plant for his own requirements, although the Stroud, the Aero, and the Raymond mills can be obtained in very small sizes. Many a customer will not need anything like the continuous output of even one of these small mills, but would gladly purchase from a central supply company.

The Pacific Coast Coal Company, of Seattle, recognising these needs, is now selling pulverised coal to small consumers.

In Chicago, also, Mr. Alonzo Kinyon has recently brought out a very neat self-contained attachment for the burning of powdered coal under central heating boilers.

The coal dust is delivered daily in steel drums. The drum is raised and turned over above the feeding hopper by means of hand-crane arms. The maximum rating of this particular plant which was inspected is 1 lb of pulverised coal per minute.

The hollow feed roller at the bottom of the tapered hopper is fitted with a motor of $\frac{1}{8}$ h.p., and the fan is driven by a $\frac{1}{4}$ h.p. motor.

This is but one method of supplying coal dust to outlying consumers. In cases where a considerable demand exists for, say, a number of small works close together, pulverised coal can be supplied through underground or overhead pipes by means of the Quigley air pressure system, just as easily as gas, water or oil are now delivered.

The supply of pulverised coal to small consumers may in time become an important industry, and the saving in fuel resulting therefrom may be worth careful consideration for suitable districts.

A new Central Supply Company at Terre Haute, Indiana, has recently started operations and from all accounts is operating with success.

CHAPTER VII.

CONCLUSIONS.

1. The advantages of burning coal in pulverised form have been definitely proved in actual practice.
2. The heat values of coals can be utilised to a far higher degree by this means of firing than by any other process.
3. In certain circumstances initial costs for pulverised coal plants are considerably less than the costs for installing producer gas plants.
4. Economy in fuel consumption of from 20 per cent. to 50 per cent. can in many cases be effected by the use of coal in pulverised form.
5. There is little or no economy to be effected by the introduction of pulverised coal burning apparatus, in substitution for existing efficient mechanical stoker installations, but for initial installations the latter plant can be installed at approximately the same if not at a lower inclusive cost and will show increased overall economies over mechanical stokers.
6. Almost any grade or quality of fuel, anthracite, bituminous, lignite or peat, can be used efficiently in certain circumstances, in pulverised form.
7. High ash fuels, containing 30 per cent. or 40 per cent. ash can in some cases be used.
8. Large quantities of what is considered waste coal can be used to good purpose, and that culm and slack heaps at mines can be at once turned to profitable account.
9. In suitably designed plants there is practically no danger whatever of the possible explosion of coal dust.
10. With the precautions as to limited storage recommended, spontaneous combustion introduces no apparent difficulties.
11. That the slag or dust resulting from the ash in coals can be conveniently and effectively handled and removed from all classes of melting and heat treatment furnaces, stationary boilers and locomotives, small furnaces such as rivet-heating furnaces being an exception.
12. A very important start has been made in connection with the firing of large power house boiler plants. The results given at the new 200,000 k.w. Super Power Station at Milwaukee certainly indicate that this method of firing power house boilers is likely to develop with increased rapidity.
13. In view of the continued interest on the part of important shipping companies in this system of firing marine boilers some progress is to be looked for in the near future.
14. Owing to the very considerably reduced amount of labour incidental to a pulverised coal plant, as compared with hand firing and, in certain cases, stoker firing, the labour saving is a most important feature introduced by this system of burning coal.
- Saving in labour is particularly marked in connection with the firing of railway locomotives by this means and incidentally conditions are greatly improved for the operators.
15. In view of the smokeless combustion of pulverised coal in metallurgical furnaces, and especially in puddling furnaces, for boiler firing and for locomotives, the abatement of smoke nuisances in large cities by this means can be accomplished to an appreciable extent.

APPENDIX I.

SYSTEMS INVESTIGATED.

1. **Quigley System.**—Quigley Furnace Specialities Co., 26, Courtland Street,
New York.
Mr. Quigley, Mr. Kimber and Mr. Renkin.
2. **Fuller System.**—Fuller Engineering Co., 50, Church Street, New York.
Col. Fuller, Mr. Rinehart, Mr. Barnhurst, Mr. Fitch, Mr. Riley, Mr. Shields.
3. **Holbeck System.**—The Bonnot Company, Canton, Ohio.
Mr. Holbeck, Mr. Bonnot, Mr Herrington.
4. **Muhlfeld System.**—Locomotive Pulverised Fuel Co., 30, Church Street, New
York.
Mr. Muhlfeld, Mr. Carachristi. Mr. Savage.
5. **Pruden System.**—Powdered Coal Engineering and Equipment Co., Washington
Boulevard, Chicago
Mr. Pruden, Mr. Wilcox.
6. **Covert System.**—Heyl and Patterson, Pittsburg.
Mr. E. C. Covert.
7. **Bergman System.**—The American Industrial Engineering and Equipment
Monadnock Building, Chicago.
Mr. L. H. Bergman.
8. **Aero System.**—Aero Pulverizer Co., 120, Broadway, New York.
Mr. Fredk. Seymour.
9. **Kinyon System.**—Mr. Alonzo, Kinyon, Chicago.
(Supply systems for domestic purposes, steam raising for heating industrial
buildings, hotels, etc.)
10. **Stroud System.**—E. H. Stroud & Co., Fullerton Avenue, Chicago.
(No close investigation of this system was made.)
In addition to the data given the writer by these gentlemen, he was also fortunate in obtaining from the officials of the Carnegie Steel Co. descriptions and figures concerning pulverised coal plants that they themselves design and instal in the various works controlled by this company. Mr. Coutant, late of the Quigley organisation, also generously furnished copies of working results, tables and plants which he has collected during his experience as operating engineer on several important undertakings.

“ NEW SYSTEMS.”

The art of burning fuel in pulverised form is ever embracing additional engineers and Plant Equipment Supply Companies in America. Two new names have come to the writer's knowledge and these are recorded for the benefit of readers interested in this subject.

Combustion Economy Corporation, Chicago, Ill.
Supply the “ Grindlo ” Burners and Conveying System.

Ground Coal Company, Chicago, Ill.
Supply the “ Arrowood ” Burners and System.

APPENDIX II.

INSTALLATIONS VISITED.

- Dilworth Porter & Co., Pittsburg, Pa.**
 Continuous and ordinary billet heating furnaces. Spike rod heating furnaces.
- A. M. Byers & Co., Pittsburg, Pa.**
 Muck bar bushelling furnaces, wrought iron pipe, skelp welding furnaces.
- A. M. Byers, Girard, O.**
 Puddling Furnaces. (Proposition now being considered.)
- The Midvale Steel Co., Philadelphia, N.Y.**
 Heavy billet and ingot heating furnaces for big gun forgings.
- Standard Tin Plate Co., Cannonsburg, Pa.**
 Steel plate, sheet and pair furnaces, annealing furnaces, tin plating furnaces.
- Pressed Steel Car Co., McKees Rocks, Pittsburg, Pa.**
 O.H. steel furnace, forge furnaces, annealing furnaces, plate heating furnaces, rivet heating furnaces.
- Follansbee Bros., Follansbee, Pa.**
 O.H. steel furnaces, sheet and pair furnaces, galvanising kettles, continuous billet heating furnaces. (Plant in actual operation at date of inspection.)
- Carnegie Steel Co., McDonald, Ohio.**
 Continuous billet heating furnaces.
- Carnegie Steel Co., North Works, Sharron, O.**
 O.H. steel furnaces.
- Carnegie Steel Co., Donora, Nr. Pittsburg, Pa.**
 O.H. steel furnaces.
- Middletown Car Works, Middletown, Pa.**
 Small forge furnaces, rivet heating furnaces, billet heating furnaces.
- Bethlehem Steel Co., Steelton, Pa.**
 O.H. furnaces, continuous billet heating furnaces
- The Upson Nut Co., Cleveland, O.**
 Continuous billet heating furnaces.
- Ash Grove Cement Co., Chanute, Kansas.**
 Cement kilns and one steam boiler
- Missouri, Kansas & Texas Railway Shops, Parsons, Kansas.**
 Eight steam boilers and switch engine.
- Milwaukee Electric Traction and Light Co., Milwaukee, Wis.**
 Two steam boilers. Under experimental trial. (Plant not actually inspected.)
- International Harvester Co., Deering Works, Chicago.**
 Annealing furnaces.
- National Malleable Castings Co., Melrose Park, Chicago:**
 O.H. steel furnaces.
- Sizer Forge Co., Buffalo, N.Y.**
 Heavy forge furnaces for heating billets for propeller shafts.
- American Radiator Co., Buffalo, N.Y.**
 Annealing furnaces and reverberating melting furnaces.
- Union Carbide Co., Welland, Canada.**
 Lime burning for calcium carbide. (Inspection of plant refused.)
- American Iron and Steel Co., Lebanon, Pa.**
 Puddling furnaces, nut and bolt heating furnaces, O.H. steel furnaces and O.H. steel tilting furnaces.
- Oliver Iron and Steel Co., Pittsburg, Pa.**
 Some 300 small furnaces, the majority of which will be converted to pulverised fuel. Billet heating, nut and bolt, forge and rivet furnaces.

APPENDIX III.

PULVERISED FUEL USERS.

(Compiled by Mr. F. P. Coffin and published by him in the *General Electric Review*. Vol. XXI., No. 5, May, 1918.

(Slightly revised by the Author, March, 1921.)

STEAM GENERATION.

STATIONARY BOILERS.

American Locomotive Co.	Schenectady, N. Y.
² Anaconda Copper Mining Co.	Anaconda, Mont.
¹ Armstrong-Whitworth Co.	Montreal, Quebec. (Temporarily closed down.)
Ash Grove Portland Cement Co.	Chanute, Kansas.
Central Railway of Brazil ...	Barro do Pirahy, Brazil, S. A.
Choctaw Portland Cement Co.	Hartshorne, Okla.
Hudson Coal Co.	Olyphant, Pa.
¹ Lackawanna Coal Co.	Likens, Pa.
² Lima Locomotive Works, Inc.	Lima, Ohio.
¹ Milwaukee Elec. Rwy. & Lt. Co.	Milwaukee, Wis.
Missouri, Kan. & Tex. Rwy.	Parsons, Kan.
Pacific Coast Coal Co.	Renton, Wash.
¹ Puget Sound Tract. Lt. & Pwr. Co.	Seattle, Wash.
² Sizer Forge Co.	Buffalo, N. Y.
United Verde Extension Mining Co.	Jerome, Ariz.

STEAM GENERATION.

Milwaukee Electric Railway & Light Co.	Oneida, Street Works.
Milwaukee Electric (Super Power Station)	Lakeside.
Allegheny Steel Co.	Brackenridge, Pa.
Allentown Cement Co.	Allentown, Pa.
American Car & Foundry Co.	Buffalo, N.Y.
American Chain Co.	York, Pa.
Ashtabula Steel Co.	Ashtabula, Ohio.
Boulonnieres de Bogny Braux	Paris, France.
British Columbia Sugar Refinery Co.	Vancouver, B.C.
Eschweiller Berg Works	Kohlscheid, Germany.
Ford Motor Co.	Detroit, Michigan.
Illinois Malleable Iron Co.	Chicago, Ill.
Maastrichtsche Zinkwit	Maatschappij, Holland.
Morriss & Co.	Oklahoma City, Okla.
Newton Steel Co.	Warren, Ohio.
St. Joseph Lead Co.	Rivermines, Mo.
Saline County Coal Co.	Chicago, Ill.
Swift & Co.	Fort Worth, Texas.
Trumbull Steel Co.	Warren, Ohio.
W. B. Uihlein Co.	Milwaukee, Mich.
West Virginia Pulp & Paper Co.	West Virginia.

STEAM LOCOMOTIVES.³

Atchison, Topeka & Santa Fe Rwy.	Fort Madison, Iowa.
⁴ Central Railway of Brazil ...	Barra do Pirahy, Brazil, S. A.
Chicago & North Western Rwy.	Chicago, Ill.
Delaware & Hudson Co.	Carbondale, Pa.
Missouri, Kan. & Tex Rwy.	Parsons, Kan.
New York Central Railroad	Albany, N.Y.
Lehigh Valley Railroad	Easton, Pa.

} Tests. Discontinued during the war period.

STEAMSHIPS.

⁵ United States Shipping Board
---	-----

METALLURGICAL INDUSTRIES.

OPEN-HEARTH FURNACES.

American Rolling Mills Co.	Middletown, Ohio.
American Steel Foundries ...	Sharon, Pa.
American Steel & Wire Co.	Donora, Pa.
Antlantic Steel Co.	Atlanta, Ga.
Armstrong-Whitworth Co.	Montreal, Quebec.
Bethlehem Steel Co.	Lebanon, Pa.
Carnegie Steel Co.	Clairton, Pa. (War measure only. Discontinued.)
Carnegie Steel Co.	Homestead, Pa. (War measure only. Discontinued.)
Carnegie Steel Co.	Sharon, Pa.
Eastern Steel Co.	Pottsville, Pa.
Follansbee Brothers	Follansbee, W. Va.
National Malleable Cast. Co.	Cleveland, Ohio.
National Malleable Cast. Co.	Melrose Park, Ill.
National Malleable Cast. Co.	Sharon, Pa.
Sharon Steel Hoop Co.	Sharon, Pa. (Discontinued.)

OPEN HEARTH FURNACES.

Manitoba Rolling Mill Corporation, Ltd.	Manitoba, Canada.
---	-------------------

BUSHELLING AND PUDDLING FURNACES.

Bethlehem Steel Co.	Lebanon, Pa
Burden Iron Co.	Troy, N.Y.
Fort Wayne Rolling Mill Co.	Fort Wayne, Ind.
London Rolling Mills	London, Ont.
Milton Manufacturing Co.	Milton, Pa.
Scranton Bolt & Nut Co.	Scranton, Pa.
St. Louis Screw Co.	St. Louis, Mo.
Union Rolling Mills	Cleveland, Ohio.

CONTINUOUS HEATING FURNACES FOR BLOOMS AND BILLETS.

'Allegheny Steel Co.	Brackenridge, Pa.
American Steel & Wire Co.	Cleveland, Ohio.
Bethlehem Steel Co.	Steelton, Pa.
Carnegie Steel Co.	Clairton, Pa. (War measure. Dis- continued.)
Dilworth-Porter Co., Inc.	Pittsburgh, Pa.
Midvale Steel Co.	Philadelphia, Pa.
National Pressed Steel Co.	Massillon, Ohio.
Oliver Iron & Steel Co.	Pittsburgh, Pa.
Union Rolling Mills Co.	Cleveland, Ohio.
Upson Nut Co.	Cleveland, Ohio.

FURNACES FOR HEATING, RE-HEATING, AND FORGING.

American Locomotive Co.	Schenectady, N. Y.
Bethlehem Steel Co.	Lebanon, Pa.
Burden Iron Co.	Troy, N. Y.
A. M. Byers Co.	Pittsburgh, Pa.
Calumet Steel Co.	Chicago Heights, Ill.
Carnegie Steel Co.	Sharon, Pa.
Carnegie Steel Co.	Youngstown, Ohio.
Dilworth-Porter Co., Inc.	Pittsburgh, Pa.
E. Dulieux	New York City.
Eastern Steel Co.	Pottsville, Pa.
Follensbee Brothers	Follensbee, W. Va.
Fort Wayne Rolling Mill Co.	Fort Wayne, Ind.
'Hubbard & Co.	Pittsburgh, Pa.
Inland Steel Co.	Chicago, Ill.
Lima Locomotive Works, Inc.	Lima, Ohio.

FURNACES FOR HEATING, RE-HEATING, AND FORGING—*contd.*

Middletown Car Co.	Middletown, Pa.
Midvale Steel Co.	Philadelphia, Pa.
Milton Manufacturing Co.	Milton, Pa.
'Newport Rolling Mill Co.	Newport, Ky.
Oliver Iron & Steel Co.	Pittsburgh, Pa.
Scranton Bolt & Nut Co.	Scranton, Pa.
Scranton Forging Co.	Scranton, Pa.
Sizer Forge Co.	Buffalo, N. Y.
Standard Steel Works	Burnham, Pa.
St. Louis Screw Co.	St. Louis, Mo.
United States Horseshoe Co.	Erie, Pa.
United States Horseshoe Co.	Manitoba, Canada.
'Verona Tool Co.	Pittsburgh, Pa.
'Warwood Tool Co.	Warwood, W. Va.
'Wood, Allan, Iron & Steel Co.	Conshohocken, Pa.

FURNACES FOR HEATING, RE-HEATING, AND FORGING.

American Car & Foundry Co.	Buffalo, N.Y.
Boulonnneries de Bogny Braux ...	Paris, France.
Detroit Seamless Tubes Co.	Detroit, Mich.
Follansbee Bros.	Toronto, Ontario.
Manitoba Rolling Mill Corporation, Ltd.	Manitoba, Canada.
Pittsburg Forge & Iron Co.	Pittsburg, Pa.
Standard Forging Co.	Indiana Harbor, Ind.

ANNEALING FURNACES FOR MALLEABLE IRON AND STEEL CASTINGS AND PLATES.

'American Malleable Co.	Owasso, Mich.
American Radiator Co.	Buffalo, N. Y.
Erie Malleable Iron Co.	Erie, Pa.
'Establishments Lemoin	Paris, France.
Follensbee Brothers	Follensbee, W. Va.
General Electric Co.	Erie, Pa.
Globe Seamless Steel Tubes Co.	Milwaukee, Wis. (Discontinued.)
International Harvester Co.	Chicago, Ill. (Deering Works.)
International Harvester Co.	Chicago, Ill. (McCormick Works.)
International Harvester Co.	Hamilton, Ont.
Kalamazoo Malleable Iron Co.	Kalamazoo, Mich.
Lima Locomotive Works, Inc.	Lima, Ohio.
National Malleable Cast. Co.	Cleveland, Ohio.
National Malleable Cast. Co.	Sharon, Pa.
'Newport Rolling Mill Co.	Newport, Ky.
Pittsburgh Malleable Iron Co.	Pittsburg, Pa.
Pressed Steel Car Co.	Pittsburg, Pa.
T. H. Symington Co.	Rochester, N. Y.

ANNEALING FURNACES FOR MALLEABLE IRON, &c.

Detroit Seamless Tubes Co.	Detroit, Mich.
Illinois Malleable Iron Co.	Chicago, Ill.
Pittsburg Malleable Iron Co.	Pittsburg, Pa.

MALLEABLE IRON MELTING FURNACES.

Ohio Malleable Co.	Columbus, Ohio.
Pittsburg Malleable Iron Co.	Pittsburg, Pa.
T. H. Symington Co.	Rochester, N.Y.
United Engineering & Foundry Co.	Canton, Ohio.

SHEET AND PAIR* AND ANNEALING FURNACES, AND TIN POTS.

'American Rolling Mills Co.	Middletown, Ohio. (War measure only. Never used.)
'Carnahan Steel Plate & Sheet Steel Co.	Canton, Ohio.

SHEET AND PAIR AND ANNEALING FURNACES, AND TIN POTS.—contd.

'Follensbee Brothers	...	...	...	Follensbee, W. Va.
'Liberty Steel Co.	...	...	...	Warren, Ohio.
'Mansfield Sheet & Tin Plate Co.	...	...	...	Mansfield, Ohio.
'McKeesport Tin Plate Co.	...	...	...	McKeesport, Pa.
'Newport Rolling Mill Co.	...	...	...	Newport, Ky.
Phillips' Sheet & Tin Plate Co.	...	...	...	Clarkshburg, W. Va.
Standard Tin Plate Co.	...	...	...	Canonsburg, Pa.
'Trumbull Steel Co.	...	...	...	Warren, Ohio.

SHEET AND PAIR FURNACES AND ANNEALING FURNACES, &c.

Ashtabula Steel Co.	...	...	...	Ashtabula, Ohio.
Newton Steel Co.	...	...	...	Warren, Ohio.
Philips Dodge Co.	...	...	...	Douglas, Ar.

GALVANIZING POTS.

A. M. Byers Co.	...	...	...	Pittsburgh, Pa.
'De Forest Sheet & Tin Plate Co.	...	...	...	Niles, O.
'Follensbee Brothers	...	...	...	Follensbee, W. Va.
'Newport Rolling Mill Co.	...	...	...	Newport, Ky.

SOAKING PITS.

'Atlantic Steel Co.	Atlanta, Ga.
---------------------	-----	-----	-----	--------------

ORE ROASTING AND NODULIZING.

Algoma Steel Corporation	...	...	...	Sault, Ste. Marie, Ont.
Bethlehem Steel Co.	...	...	...	Lebanon, Pa.
Carolina Iron Co.	...	...	...	Winston-Salem, N. C.
Central Iron & Coal Co.	...	...	...	Hold, Ala.
Charleston Ore Co.	...	...	...	Charleston, S. C.
Eastern Nodulizing Works	...	...	...	Newark, N. J.
General Chemical Co.	...	...	...
International Nickel Co.	...	...	...	Copper Cliff, Ont.
Lackawanna Steel Co.	...	...	...	Buffalo, N. Y.
Mississippi Valley Iron Co.	...	...	...	Waukon, Iowa.
Northern Iron Works	...	...	...	Standish, N. Y.
Pennsylvania Salt Mfg. Co.	...	...	...	Natrona, Pa.
Pennsylvania Salt Mfg. Co.	...	...	...	Philadelphia, Pa.
Princess Furnace Co.	...	...	...	Glen Wilton, Pa.
Spanish-American Iron Co.	...	...	...	Cuba.
Virginia Coal & Coke Co.	...	...	...	Middleboro, Ky.

ORE ROASTING AND NODULIZING.

Spanish American Iron Co.	Cuba.
---------------------------	-----	-----	-----	-------

COPPER ORE ROASTING AND SMELTING.

American Smelting & Ref. Co.	...	...	...	Garfield, Utah.
'American Smelting & Ref. Co.	...	...	...	Hayden, Ariz.
American Smelting & Ref. Co.	...	...	...	Maurer, N. J.
'American Smelting & Ref. Co.	...	...	...	Tacoma, Wash.
Anaconda Copper Mining Co.	...	...	...	Anaconda, Mont.
Anaconda Copper Mining Co.	...	...	...	Great Falls, Mont.
Canadian Copper Co.	...	...	...	Copper Cliff, Ont.
'Furukawa Mining Co.	...	...	...	Tokyo, Japan.
Lake Superior Smelting Co.	...	...	...	Dollar Bay, Mich.
Nevada Cons. Copper Co.	...	...	...	McGill, Nev.
River Smelting & Ref. Co.	...	...	...	Florence, Colo.
Société des Mines de Cuivre de Catamont	...	...	...	Chagres, Chili.
'United Verde Copper Co.	...	...	...	Clarkdale, Ariz.
United Verde Ex. Mining Co.	...	...	...	Jerome, Ariz.

COPPER ORE ROASTING AND SMELTING.

Cerro de Pasco Copper Corporation	...	Peru.
Nicholls Copper Co.	...	Long Island, N.Y.
Wallaroo & Moonta Mining Co.	...	Australia.

ZINC INDUSTRY.

Bartelsville Zinc Co.	...	Collinsville, Okla.
Edgar Zinc Co.	...	Cherryvale, Kan.
River Smelting & Ref. Co.	...	Florence, Colo.
Societe des Mines du Djebel, Ressas	...	Tunis, North Africa.

GOLD AND SILVER INDUSTRIES.

Granite Gold Mining Co.	...	Victor, Colo.
'River Smelting & Ref. Co	...	Florence, Colo.

CHEMICAL AND OTHER INDUSTRIES.**CEMENT KILNS.***Summary of Portland Cement Kiln Fuels in 1916.*

—	No. of Plants.	No. of Kilns.	Barrels of Cement.	Percentage of Total.
Coal ...	87	643	74,844,608	81·9
Coal and Oil ...	2	32	4,948,917	5·4
Coal, Oil and Gas ...	1	5	914,531	1·0
Coal and Gas ...	1	7	697,410	·8
Oil ...	17	96	8,041,926	8·8
Oil and Gas ...	2	13	957,797	1·0
Producer Gas ...	1	1	76,951	0·1
Natural Gas ...	2	10	1,039,963	1·1
	110	807	91,521,198	100·0

All the coal used is burned in pulverised form

The plants using fuel oil are located in the states where oil is the principal regional fuel, such as Washington, Oregon, California, Arizona, and Texas. These five states contain 21 cement plants, while only 18 plants use oil, either wholly or in part. Some foreign plants also have American pulverised-fuel equipment.

CALCINING KILNS.*Gypsum Rotaries and Kettles,*

Manitoba Gypsum Co.	...	Winnipeg, Man.
Niagara Gypsum Co.	...	Oakfield, N. Y.
Plymouth Gypsum Co.	...	Fort Dodge, Iowa.

Lime Burning

'Air Nitrates Co.	...	Sheffield, Ala.
Bare Paper Co. (Lime Sludge)	...	Roaring Springs, Pa.
Campbell Stone Co.	...	Afton, Mich.
Industrial Limestone Co.	...	Nazareth, Pa.
Lackawanna Steel Co.	...	Buffalo, N. Y.
"Solvay Process Co.	...	Syracuse, N. Y.
Tennessee Coal, Iron & Railroad Co.	...	Birmingham, Ala.
Union Carbide Co.	...	Niagara Falls, N. Y.
Union Carbide Co.	...	Sault Ste. Marie, Mich.
Union Carbide Co.	...	Welland, Ont.
Union Carbide Co.	...	Norway.

LIME BURNING.

Air Nitrates Corporation ...	... ... ...	Birmingham, Ala.
Union Carbide Co. ...	... ... ...	Sweden.

Refractory Materials.

¹⁰ Coplay Portland Cem. Mfg. Co. ...	... ...	Coplay, Pa.
Dolomite Products Co. ...	... ... ...	Maple Grove, Ohio.
¹⁰ Harbison-Walker Refractories Co. ...	... ...	Chester, Pa.
Northwest Magnesite Co. ...	... ... ...	Chowellah, Wash.

FERTILISER INDUSTRY.*Phosphate Rock.*

Armour Fertiliser Works	Bartow, Fla.
-----------------------------	-------------	--------------

Tankage and Garbage.

International Agr. Corp. ...	... ... ...	Lockland, Ohio.
International Agr. Corp. ...	... ... ...	Norfolk, Va.

*Potash Extraction.**From Sericite¹¹*

American Potash Co.	Portland, Ga.
-------------------------	-------------	---------------

From Greensand and Marl.

Atlantic Potash Co.	Stockertown, Pa.
-------------------------	-------------	------------------

From Alunite (with alumina filter-cake as by-product).

Florence Mining & Milling Co. ...	... ...	Marysville, Utah.
Mineral Products Corp. ...	... ...	Marysville, Utah.

Materials Rich in Potash.

American Chem. & Min. Co.	Atlanta, Ga.
-------------------------------	-------------	--------------

*Feldspar Shale (Gneiss) Calcined in rotary dryers for fertiliser filler.**Cement Kiln Flue Dust*, rich in potash, is recovered by the Cottrell Electrostatic Precipitation Process at the following plants using pulverised coal:—

Alpha Portland Cement Co. ...	... ...	Alsen, N. Y.
Security Cement & Lime Co. ...	... ...	Hagerstown, Md.

MISCELLANEOUS INDUSTRIES.*Bauxite Ore (Rotary Dryer).*

¹ American Bauxite Co.	Bauxite, Ark.
---------------------------------------	-------------	---------------

Chemicals (Rotary Kilns).

Clinchfield Products Corp.	Johnson City, Tenn.
--------------------------------	-------------	---------------------

To the above list may be added the following installations:

Silver and Lead Refining.

Bunker Hill Sultivan Mining & Concentration Co.	Kellog, Idaho.
---	-------------	----------------

Heating and Annealing Furnaces.

Alan Wood, Iron & Steel Co.	Conshohocken, Pa.
---------------------------------	---------	-------------------

Dolomite Burning.

Transue Williams & Co.	Alliance, Ohio.
----------------------------	-------------	-----------------

Forging.

Kennedy Refractories Co.	Bainbridge, Pa.
------------------------------	-------------	-----------------

Baking Electrodes.

National Carbon Co.	Niagara Falls, N.Y. (Works at which used, have been closed. Pulverised Coal satisfactory.)
-------------------------	-------------	--

Boilers.

Whitaker Glesner & Co. Wheeling, W. Va.
¹²Susquehanna Collieries Co. Lykens, Pa.

- ¹ Denotes installations under construction or just starting up.
 - ² Waste heat or direct-firing.
 - ³ Five American railroads have recently been experimenting with pulverised coal on single locomotives.
 - ⁴ Twelve locomotives in operation.
 - ⁵ One 9,600-ton freight steamship authorised.
 - ⁶ Steel bars are heated in these furnaces for rolling into sheets. One of the operations consists in rolling the sheets in pairs.
 - ⁷ Copper, zinc, silver, and gold from the same ore, which is treated in a reverberatory furnace.
 - ⁸ Cement in 1916, Mineral Resources of the U.S. U.S. Geological Survey
 - ⁹ Small sizes of limestone only.
 - ¹⁰ Magnesite.
 - ¹¹ Sericite is a variety of mica made up of small elongated silver-coloured shreds. It resembles talc.
 - ¹² Burning Anthracite Culm.
-

APPENDIX IV.**DIFFICULTIES IN THE USE OF PULVERISED COAL.**

Much has been written from time to time about the merits and advantages of pulverised coal.

On the other hand what are its drawbacks?

On this side of the question the author would enumerate some of the disadvantages and in particular refer to important points to be considered when investigation of the subject is to be gone into and plant erected.

The difficulties and disadvantages as these would apparently present themselves to an investigator of the subject are briefly:—

1. Spontaneous combustion and storage difficulties.
2. Danger of explosion.
3. Difficulty of transportation.
4. Reabsorption of moisture.
5. Preparation costs.
6. Capital expenditure for comprehensive plants.

Due consideration and thought must be given to the quality of fuel to be pulverised and stored. The length of time that this latter becomes feasible or safe, depends on the nature of the fuel, the temperature at which it is delivered into the storage bins, and the initial content of moisture and volatile matter. Anthracite is the safest coal, whilst lignite is the most dangerous, the ordinary bituminous coal being intermediate.

The danger of explosion is a disadvantage but not more so than that appertaining to coal gas or even oil. The danger of explosion in a mill house exists when leaky and faulty plant is permitted to exude coal dust into the atmosphere. This can and should be prevented. What cannot be prevented is the pounding of a nut or broken beater arm in a "dry grinding" mill until the metal fragment becomes red or even white hot, thus igniting the coal dust and air mixture in the mill and causing an explosion. For this reason slow-speed rotary mills fitted with grinding rings are preferable to the higher-speed beater-arm type of machine.

It has been suggested that the danger of using pulverised coal is analogous to the danger existing from coal dust in a mine. A coal-dust-laden mixture explosion in a colliery working must be likened to the actual burning of pulverised fuel in air inside the combustion chamber of a furnace rather than to suggest that because of colliery explosions pulverised coal is per se a dangerous and explosive substance. Recent explosions in America in pulverised coal equipment have been generally due to mixing and conveying the fuel in air, and therefore risking conditions analogous to colliery explosions.

If one wishes pulverised coal to explode or burn one mixes with it the requisite amount of air, otherwise one conveys the powdered fuel by mechanical means and only introduces it into the air supply at the furnace burners or at most through short lengths of small piping when fuel must be previously mixed with air.

The conveyance of pulverised coal through a works was until recently a troublesome matter, but the difficulties no longer exist; the compressed-air transmission through ordinary three-inch or four-inch pipes and the pumping system, through similar pipes, have made the conveying of pulverised coal an easy and safe proposition.

In wet climates the reabsorption of moisture may well result in the blocking of conveyor pipe lines and possibly in the commencement of spontaneous combustion in storage bins. For such countries screen separator types of pulveriser mills should be used, for with these there is a minimum of moisture-carrying air in contact with the fuel in the mill. For the same reason coal dust cannot possibly be conveyed in an air current through trunk mains, whilst screw conveyors also contain much air space and should be avoided. The quantity held in storage at all points should also be a minimum; in fact, pulverised coal in wet climates should be burned as soon after it is "made" as possible.

Preparation, conveying and burning costs must always be added to the cost of raw coal, and at present-day rates for labour, plus interest allowance on capital, overall preparation costs vary considerably, say 8s. 7d. and 5s. 3d. per ton for plants of a daily capacity of 30 tons to 300 tons. Whether fuel of a cheaper quality can be used for equal duty, or whether reduced consumption of standard-grade coal, plus other savings, outweigh the increased cost of pulverised fuel for any capacity of plant, is a matter for calculation.

The greatest disadvantage is the heavy capital expenditure to be contended with. If £10,000 per annum could be returned on an expenditure of £100 every consumer of fuel would put down a plant, but when this return of £10,000 per annum means the dislocation and scrapping of existing plant and the outlay of £10,000, or perhaps £20,000, on new plant it is only reasonable that a would-be user must be firmly convinced on all points before embarking upon such a project. Until either design is modified in order to lower the initial capital cost or until more plants giving unqualifiedly successful and economical results in England and in Europe, can be actually seen in operation, the real expansion and general use of pulverised coal will perhaps be somewhat slow.

L. C. H.

APPENDIX V.

BIBLIOGRAPHY.

- LIST OF REFERENCES COMPILED BY ENGINEERING SOCIETIES LIBRARY (U.S.A.).
- FUEL POSSIBILITIES IN STEEL MAKING.—*Iron Age*, November 6, 1913, p. 1056-1059.
Paper read before the American Iron and Steel Institute, by William Whigham. The author discusses the use of pulverised coal as a fuel for open-hearth furnaces.
- IMPROVED PULVERISED FUEL FEED DEVICE.—*Iron Age*, November 6, 1913, p. 1024.
Brief description of the Dunn apparatus, especially intended for cement kilns, but used also in the nodulizing of iron ore.
- WIDER UTILISATION OF PULVERISED COAL, H. R. Barnhurst.—*Iron Age*, October 23, 1913, p. 906-908. Part of discussion of paper by James Lord on The Use of Pulverised Fuel in Metallurgical Furnaces, read before the Engineers' Society of Western Pennsylvania.
- POWDERED COAL FOR OPEN HEARTH FURNACES.—*Iron Age*, October 16, 1913, p. 855.
Abstract from the *Coal and Coke Operator*.
- USE OF PULVERISED COAL AS A FUEL FOR BOILERS, R. C. Carpenter.—*Sibley Journal of Engineering*, December, 1913, p. 85.
- COAL-DUST FIRED BOILER.—*Indian Engineering*, November 29, 1913, p. 301.
- PROGRESS IN FUEL UTILISATION.—*Mining and Scientific Press*, October 25, 1913, p. 638.

- BUFFALO GRAIN ELEVATOR DUST EXPLOSION.**—*Engineering News*, July 31, 1913, p. 223-24. Reprinted in the *National Fire Protection Association Quarterly*, October, 1913, p. 149-151. Mention is made of the danger of explosions in connection with the burning of powdered coal.
- POWDERED FUEL AND EXPLOSIONS.**—*Railway Age Gazette*, July 18, 1913, p. 83-84. Letter by W. D. Wood.
- USE OF PULVERISED COAL IN METALLURGICAL FURNACES**, James Lord. Engineers' Society of Western Pennsylvania, Proc. October, 1913, p. 363-372; discussion, p. 371-417. With bibliography.
- PULVERISED FUEL FOR BOILER FIRING**, C. H. Wright.—*Electrical World*, March 15, 1913, p. 567-569.
- PULVERISED COAL AS A FUEL**, H. R. Barnhurst.—*Metallurgical and Chemical Engineering*, March, 1913, p. 127-129. With special reference to metallurgical furnaces.
- POWDERED COAL AS FUEL**.—*Indian Engineering*, August 16, 1913, p. 91. Briefly discusses its use as a locomotive fuel.
- POWDERED FUEL FOR LOCOMOTIVES**, Walter D. Wood.—*Railway Age Gazette*, July 4, 1913, p. 13-15; August 1, p. 174.
- PULVERISED COAL AS A CHEAP FUEL**.—*Automobile*, June 5, 1913, p. 1177. Letter asking questions as to the use of pulverised coal. Answers are given.
- PROBLEM OF BURNING PULVERISED COAL**, Sterling H. Bunnell.—*Iron Age*, September 18, 1913, p. 618.
- USE OF PULVERISED COAL AS FUEL FOR METALLURGICAL FURNACES**, H. R. Barnhurst.—American Institute of Mining Engineers, Bull., October, 1913, p. 2523-2532; discussion, December, 1913, p. 2856-2863.
- PULVERISED COAL AS A FUEL**, A. W. Raymond.—*Metallurgical and Chemical Engineering*, February, 1913, p. 108-109. On the use of pulverised coal in metallurgical furnaces and in cement burning.
- BURNING OF POWDERED COAL**, W. E. Porter.—*Industrial World*, vol. 47, p. 146-147, February 3rd 1913.
- POWDERED COAL AS FUEL**, W. S. Quigley.—*Railway and Engineering Review*, November 15, 1913, p. 1067-1068. Paper read before the American Foundrymen's Association.
- SMALL COAL AND DUST: ITS PRODUCTION, PREVENTION, TREATMENT, AND UTILISATION, WITH SPECIAL REFERENCE TO DRY MINES**, J. Drummond Paton.—Institution of Mining Engineers, Trans., vol. 45 pt. 3, p. 421-446; discussion, p. 446-449, 1912-1913. Same in Manchester Geological and Mining Society, Trans., vol. 33, pt. 6, p. 198-223; discussion p. 223-226, 1912-1913. Results of official tests made by the Stirling Boiler Co.
- FIRING SOFT COAL SCREENINGS**, John S. Leese.—*Mechanical World*, vol. 51, p. 160-191, 1912.
- DUST FUEL BOILER AND ITS USES**, H. V. Hart Davis.—Manchester Geological and Mining Society, Trans., vol. 22, p. 224-233; discussion, p. 223-242, 1912. Abstract in *Iron and Coal Trades Review*, February 23, 1912, p. 198-299; *Engineering Magazine*, March, 1913, p. 936-938.
- PULVERISED COAL AS AN ECONOMICAL STEAM FUEL**.—*Steam*, May, 1912, p. 135-138. A table shows results obtained with a Bettington boiler.
- METHODS OF BURNING ANTHRACITE COAL DUST**.—Wm. Kavanagh.—*Electrical World*, December 7, 1912.
- RECENT IMPROVEMENTS AND ADDITIONS TO THE SMELTING PLANT OF THE CANADIAN COPPER COMPANY**, D. H. Browne.—Canadian Mining Institute, Trans., vol. 15, p. 115-122, 1912.
- COMBUSTION OF PULVERISED COAL**, L. S. Hughes.—American Institute of Chemical Engineers, Trans., vol. 4, p. 347-349, 1911.
- PULVERISED COAL, A NEW FUEL**, Wm. D. Ennis.—*Automobile*, vol. 25, p. 620-621, 1911. Contains paragraph on the use of powdered coal under steam boilers.
- BETTINGTON BOILERS FOR PULVERISED FUEL**.—*Railway News*, vol. 96, p. 1422-1423, 1911. Gives results of tests.
- DE L'EMPLOI DES POUSSIERS DANS LES FOYERS MECHANIQUES**, J. Izart.—*L'Electricien*, vol. 41, p. 54-57, 1911.
- FIRING BOILERS WITH PULVERISED COAL**, W. S. Worth.—*Power*, vol. 33, p. 264-267, 1911. Tests were made at the Henry Phipps plant, Pittsburg.

- THE ROTARY KILN, Ellis Soper.—American Society of Mechanical Engineers, Journal, October, 1910; discussion, April 1911. In the paper and in the discussion reference is made to the earliest successful use of pulverised coal for cement manufacture.
- USE OF PULVERISED COAL FOR FOUNDRY PURPOSES, Richard K. Meade.—American Foundrymen's Association, Trans., vol. 18, p. 39-45, 1909. Abstract in Foundry, vol. 34, p. 196-198, 1909. The author gives an estimate of the cost of pulverising.
- COAL DUST FIRING OF REVERBERATORY FURNACES, Edward G. Thomas.—*Engineering and Mining Journal*, vol. 85, p. 269-270, 1908.
- COAL DUST FIRING FOR REVERBERATORY FURNACES, Charles F. Shelby.—*Engineering and Mining Journal*, vol. 85, p. 541-544, 1908.
- FEEDING PULVERISED COAL TO FURNACES, R. Cederblom.—*Power*, vol. 28, p. 299-300, 1908.
- SOME INDUSTRIAL APPLICATIONS OF PULVERISED COAL, W. D. Ennis.—Brooklyn Engineers' Club, Proc., vol. 12, p. 183-200; discussion, p. 201-217, 1908. The author discusses various methods of grinding coal and special applications such as firing of steam boilers and industrial furnaces.
- PULVERISED COAL AND ITS INDUSTRIAL APPLICATIONS, W. D. Ennis.—*Engineering Magazine*, vol. 34, p. 463, 577, 1907-1908. Costs are given.
- USE OF PULVERISED FUEL FOR HEATING METALLURGICAL FURNACES, Richard K. Meade.—American Institute of Chemical Engineers, vol. 1, p. 98-115, 1908.
- USING SOFT COAL SCREENINGS.—*Power*, vol. 29, p. 706, 1908.
- ECONOMY OF THE LONG KILN, E. C. Soper.—American Society of Mechanical Engineers, Trans., vol. 29, p. 143-148; discussion, p. 149-158, 1907. In the discussion Professor William D. Ennis gives some figures relative to the cost of pulverised coal.
- SCHWARTZKOPFF SYSTEM OF COAL DUST FIRING, P. M. Pritchard.—Liverpool Engineering Society, Trans., vol. 28, p. 154-156; discussion, p. 166-176, 1907. An account of tests.
- DUST FUEL STOKERS AND AUXILIARY PLANT, W. R. Harrison.—Leeds University Society, December 10, 1906.
- BAENSCH-FEUERUNGEN ZUR VERFEUERUNG VON TEER, KOHLENSTAUB, ETC., Wegener.—*Asphaltkunde u. Teer Industrie Zeitung*, vol. 6, p. 4, 1906.
- COAL PULVERISER AND AUTOMATIC STOKER.—*American Electrician*, vol. 14, p. 196-197, 1906. Description of "Ideal" fuel feeder.
- POWDERED COAL FIRING FOR STEAM BOILERS, Geo C. McFarlane.—*Engineering and Mining Journal*, vol. 81, p. 901-902, 1906. Comparison of costs of hand firing and powdered-coal firing.
- PROBLEM OF SMOKE ABATEMENT, Wm. H. Bryan.—*American Machinist*, vol. 29, pt. 2, p. 52-54, 1906. Powdered coal is compared with other fuels as to cost, efficiency.
- COAL DUST FIRING OF REVERBERATORY MATTE FURNACES, S. Severin, Sorensen.—*Engineering and Mining Journal*, vol. 81, p. 274-276, 1906. With diagrams of smelting results.
- COAL DUST FIRING FOR STEAM BOILERS.—*Engineer* (London), vol. 99, p. 502-503, 1905. Gives results of tests made with the Schwartzkopff apparatus by C. E. Stromeyer, of the Manchester Steam Users' Association.
- FIRING WITH COAL DUST, Eustace Carey.—*Society of Chemical Industry Journal*, vol. 24, p. 369-371; discussion p. 371-372, 1905. Abstract in *Engineering and Mining Journal*, vol. 80, p. 1113-1114, 1905.
- UTILISATION OF LOW-GRADE FUELS FOR STEAM GENERATION, W. Francis Goodrich.—*Engineering Magazine*, vol. 30, p. 346-354, 1905.
- ROAD TESTS OF BROOKS PASSENGER LOCOMOTIVES, E. A. Hitchcock.—American Society of Mechanical Engineers, Trans., vol. 26, p. 290-306; discussion, p. 306-311, 1905. In the discussion on p. 310-311 the use of pulverised coal as a fuel for locomotives was considered.
- COAL DUST FIRING AS APPLIED TO ANNEALING FURNACES.—*Iron and Coal Trades Review*, vol. 70, p. 1999, 1905. Schwartzkopff system.
- COMPARATIVE BOILER TESTS WITH ORDINARY AND PULVERISED COAL FIRING.—*Engineering Record*, vol. 49, p. 342, 1904.

- BURNING POWDERED COAL, H. J. Travis.—*Power*, vol. 24, p. 168-196, 271, 1904. Tests of various systems, also comparative tests of hand-fired and pulverised-fuel boilers.
- POWDERED COAL AND STEEL ANNEALING, J. H. Travis.—*American Machinist*, vol. 27, pt. 1, p. 791-792, 1904.
- USE OF PULVERISED COAL FOR FUEL UNDER STEAM BOILERS, J. M. Sweeney.—*Western Society of Engineers Journal*, vol. 9, p. 141-149; discussion, p. 149-160, 1904. With tables showing evaporation secured from pulverised fuel and hand-fired coal.
- TESTS OF PULVERISED FUEL.—*Engineer (U.S.)*, vol. 41, p. 259-260, 1904. Tests were made at the plant of the International Harvester Company.
- BURNING OF PULVERISED COAL, C. O. Bartlett.—*Association of Engineering Societies Journal*, vol. 31, p. 44-48, 1903; *Railway and Engineering Review*, vol. 43, p. 568-569, 1903; *Engineer (U.S.)*, vol. 50, p. 563-564, 1903. Paper read before the Civil Engineers' Club, of Cleveland. Gives estimated cost of outfit for about 40 tons per day of 10 hours.
- BURNING POWDERED COAL UNDER BOILERS.—*Power*, vol. 23, p. 434-437, 1903.
- POWDERED FUEL.—*Power*, vol. 23, p. 561, 1903. Letter by W. E. Crane.
- PULVERISED FUEL.—*Engineer (U.S.)*, vol. 40, p. 272-275, 1903. Costs are given and an estimate of the saving made by pulverising the coal.
- IMPROVED SYSTEM OF BURNING COAL DUST.—*Engineer (U.S.)*, vol. 40, p. 93-94, 1903. The Rowe system.
- A ROTARY BRUSH SYSTEM OF FEEDING PULVERISED FUEL TO FURNACES.—*Engineering News*, vol. 47, p. 147, 1902. Test of Schwartzkopff system.
- SYSTEM OF BURNING COAL DUST.—*American Miller*, vol. 30, p. 1006, 1902. Bartlett and Snow system.
- UEBER DEN GEGENWAERTIGEN STAND DER KOHLENSTAUBFEUERUNG, HAEUSSERMANN.—*Gewerblich technischer Ratgeber*, vol. 1, p. 227-229, 1902.
- BURNING COAL DUST WITHOUT SMOKE.—*Iron Age*, November 6, 1902, p. 10-12.
- PULVERISED FUEL FOR POWER PLANTS, Gasche (Aero Pulveriser).—*Railway Gazette*, vol. 34, p. 446-467, 1902. Gives summary of results of boiler trials.
- KESSELFEUERUNG MIT PULVERISIERTER KOHLE ("Pulverisator cyclon," "Aero-Pulverisator").—*Liepziiger Monatsschrift fur Textil Industrie*, vol. 17, p. 479, 1902.
- A NEW SYSTEM FOR BURNING POWDERED COAL.—*Engineering News*, vol. 48, p. 548, 1902. Rowe and Bender system.
- THE ROWE SYSTEM OF BURNING PULVERISED COAL.—*Engineering Record*, vol. 46, p. 592, 1902.
- PULVERISED COAL BURNING IN CHICAGO.—*American Electrician*, vol. 14, p. 13-14, 1902.
- PULVERISED FUEL FOR POWER PLANTS.—*Railroad Gazette*, vol. 24, p. 466-467, 1902. With tables giving summary of results of boiler trials and heat balance for dust and fuel test.
- KOMBINIERTE KOHLENSTAUBFEUERUNG.—*Zeitschrift für Beleuchtungswesen*, vol. 7, p. 332-333, 1901.
- KOHLENSTAUBFEUERUNG.—*Ruhl. Kraft*, vol. 18, pt. 1, p. 35-37, 1901.
- POWDERED FUEL FOR BOILER FURNACES AT THE ALPHA CEMENT COMPANY'S WORKS, ALPHA, N.J.—*Engineering News*, vol. 45, p. 452-453, 1901.
- A NEW METHOD OF BURNING POWDERED FUEL.—*Engineering News*, vol. 45, p. 178-179, 1901. Description of Westlake system, with results of tests.
- THE AERO SYSTEM OF PULVERISED FUEL COMBUSTION.—*Engineering Record*, vol. 43, p. 506, 1901.
- PULVERISED FUEL, R. A. Douglas.—*American Electrician*, vol. 13, p. 434-435, 1901.
- TWO RECENT SYSTEMS FOR BURNING POWDERED COAL.—*Engineering News*, vol. 46, p. 415-416, 1901. Cyclone and Aero Pulveriser systems.
- FREITAG'S KOHLENSTAUB.—*Feuerung. Kraft*, vol. 17, p. 5-6, 1900.
- BURNING OF PULVERISED COAL.—*Engineering Record*, vol. 42, p. 241-242, 1900. Editorial note on the use of pulverised coal in rotary cement kilns.
- BURNING PULVERISED COAL.—*Railway and Engineering Review*, vol. 40, p. 560-562, 1900.
- BURNING POWDERED COAL IN STATIONARY BOILERS.—*Engineering Record*, vol. 42, p. 615-616, 1900. Tests with Westlake apparatus.
- EMPLOI DU CHARBON PULVERISE DANS LES FOYERS DES CHAUDIERES ET DES FOURLS METALLURGIQUE (systeme Schwartzkopff), A. Halleux.—*Revue Universelle des Mines*, vol. 46, p. 21-34, 1899.

- KOHLENSTAUBFEUERERGEN (Zusammenstellung der verschiedenen Erfindungen und Patente).—*Schweizerische Bauzeitung*, vol. 34, p. 4-6, 1899.
- USE OF COAL DUST AS FUEL FOR BOILERS, Count Caracristi.—*Iron and Coal Trades Review*, vol. 58, p. 643, 1899.
- Die FREITAGSCHE KOHLENSTAUBFEUERUNG, L. Kaufmann.—*Zeitschrift des Verines deutscher Ingenieure*, vol. 43, p. 988-992, 1899.
- THE UTILISATION OF COAL SLUDGE AND COAL DUST.—*Colliery Guardian*, vol. 77, p. 477, 1899. Abstract from Neues Saarbrueckener Gewerbeblatt.
- FREITAG APPARATUS FOR COAL DUST FUEL.—*Colliery Guardian*, vol. 78, p. 542-543, 1899. Abstract of article by L. Kaufmann in *Zeitschrift des Verines deutscher Ingenieure*.
- BURNING Low-PRICED FUEL, W. H. Wakeman.—*American Machinist*, vol. 22, p. 101, 1899.
- UEBER VERWERTUNG VON KOHLENSCHLAMM UND KOHLENSTAUB.—*Oest Zeitschrift fur Berg u. Huttenwesen*, vol. 57, p. 127-129, 1899. Abstract in *Institution of Civil Engineers, Proc. vol. 136*, p. 421-422, 1898-1899.
- CHAUFFAGE DES CHAUDIERES AU CHARBON PULVERISE (systeme F. Frost).—*Revue Industrielle*, vol. 29, p. 16, 1898.
- NEW COAL DUST FURNACES.—*Iron and Coal Trades Review*, vol. 47, p. 177-178, 1898. Pinther, Russell, Lester & Ernst, Peck and Patterson systems.
- VERSUCHERGEBNISSE DER DE CAMPSCHEN KOHLENSTAUBFEUERUNGEN, Schnieder.—*Mitteilungen aus der Praxis des Dampfkessel und Dampfmaschinenbetriebes* vol. 20, p. 76, 1897.
- NOVELTIES IN COALDUST FIRING APPARATUS.—*Colliery Guardian*, vol. 76, p. 514, 1898. Abstract from *Tonindustrie Zeitung*.
- RUEHM'S APPARATUS FOR BURNING POWDERED COAL.—*Engineering (Lond.)*, vol. 63, p. 72, 1897.
- BURNING POWDERED COAL UNDER STEAM BOILERS.—*Engineering News*, vol. 38, p. 189-190, 1897. Wegener system.
- NEUERUNGEN AN KOHLENSTAUBFEUERUNGEN.—*Dingler's Polytechnische Journal*, vol. 305, p. 272-276, 1897.
- CHAUFFAGE AU PULVERIN DE CHARBON, Vacquiers.—*La Vie Scientifique*, 1897, pt. 1, p. 253-254.
- CHAUFFAGE DES CHAUDIERES AU CHARBON PULVERISE, P. Chevillard.—*Revue Industrielle*, vol. 28, p. 162, 294, 385, 1897.
- DIE VERWENDUNG DER KLEINKOHLE, Moriz, Caspaar. Oest.—*Zeitschrift fur Berg u. Buttenwesen*, vol. 45, p. 373, 401, 1897.
- KOHLENSTAUBFEUERUNG UND VERMAHLUNG DER KOHLE, Warlich.—*Dampf*, vol. 41, pt. 1, p. 49-51 (1897).
- RUHL'S APPARATUS FOR BURNING POWDERED COAL. *Engineering*, vol. 63, p. 71-73, 1897.
- FORTSCHRITTE AUF DEM GEBIET DER KOHLENSTAUBFEUERUNG, Schutze.—*Dampf*, vol. 13, p. 1205, 1896.
- KOHLENSTAUBFEUERUNG APPARAT, Schutze.—*Uhlands Techniche Rundschau*, 1896, No. 3, p. 55.
- KOHLENSTAUBFEUERUNG (System Unger).—*Tonindustrie Zeit.*, vol. 20, p. 861, 1896.
- KOHLENSTAUBFEUERUNG NACH SYSTEM CORNELIUS (Deutsches Reich-Patent 78, 587).—*Glaser's Annalen fur Gewerbe und Bauwesen*, vol. 39, p. 139-140, 1896.
- KOHLENSTAUBFEUERUNGEN IM DAMPFKESSELHAUSE DES KONIGLICHEN OPERNHÄUSES IN BERLIN (Patent Ruhl).—*Centralblatt der Bauverwaltung*, vol. 16, p. 59, 1896.
- POWDERED COAL AS FUEL.—*Marine Engineer*, vol. 17, p. 433, 1896.
- ECONOMIC VALUE OF COAL DUST, W. Blakemore.—*Canadian Mining Review*, vol. 15, p. 200-201, 1896. Paper read before Ontario Mining Institute.
- COMBUSTION OF POWDERED COAL.—*Engineering (Lond.)*, vol. 61, p. 80-81, 1896. Experiments made by Mr. Bryan Donkin with the Wegener apparatus.
- BERLIN INDUSTRIAL EXHIBITION.—*Engineer (Lond.)*, vol. 82, p. 255, 1896. Brief description of coal-dust firing exhibit.
- WEGENER'S POWDERED FUEL BOILER FURNACE AND APPARATUS.—*Engineer (Lond.)*, vol. 81, p. 485-486, 1896. A brief account of experiments made by Mr. Bryan Donkin.
- COAL DUST FIRING IN THE IRON INDUSTRY.—*American Manufacturer and Iron World*, August 28, 1896, p. 300. Abstract from article by Victor von Neumann in the *Zeit. Oesterr. Ingen u. Architekten Verein*, vol. 48, p. 342, 353, 1896. The Schwartzkopff apparatus is described.

- COAL DUST FUEL.—Institution of Civil Engineers, Proc., vol. 123, p. 516-518, 1895-1896. Abstract of paper by C. Schnieder in *Mittheilungen aus der Praxis des Dampfkessel und Dampfmaschinen Betriebes*, 1895, p. 336.
- FIRING WITH COAL DUST AND COAL GRINDING PROCESSES.—Institution of Civil Engineers, Proc., vol. 126, p. 473-474, 1895-1896. Abstract of article by Messrs. Zarniko and Propfe in *Gesundheits-Ingenieur*, 1896, p. 210.
- KOHLENSTAUBFEUERUNGEN, Ferdinand Bleichsteiner.—*Oest. Zeitschrift für Berg und Huttenwesen*, vol. 44, p. 237-240, 1896.
- KOHLENSTAUBFEUERUNGEN, Forster.—*Uhlands Technische Rundschau*, 1896, No. 3, p. 24.
- KOHLENSTAUBFEUERUNGEN AUF DER BERLINER GEWERBE-AUSSTELLUNG, 1896, Schmidt—*Gesundheits-Ingenieur*, vol. 19, p. 354, 1896.
- NACHTHEILE DER KOHLENSTAUBFEUERUNGEN, Schneider.—*Alkohol*, vol. 6, p. 117, 1896.
- KOHLENSTAUBFEUERUNGEN.—*Zeit. des Vereines deutscher Ingenieure*, vol. 40, p. 432-436, 1896. Gives results of tests with different systems.
- VERSUCHE MIT DEN KOHLENSTAUBFEUERUNGEN VON SCHWARTZKOPFF UND FRIEDEBERG—*Dampf*, vol. 13, p. 502, 1896.
- HERSTELLUNG VON KOHLENSTAUB FUER KOHLENSTAUBFEUERUNGEN, Friedrich.—*Dampf*, vol. 13, p. 710, 1896.
- APPARATOS PARA LA COMBUSTION DE CARBONES MENUDOS, Celomer.—*Revista Minera*, vol. 45, p. 175, 1895. Wegener, Feirdberg and Schwartzkopff systems.
- DIE NEUEREN KOHLENSTAUBFEUERUNGS-APPARATE, B. Kosmann.—*Stahl und Eisen*, vol. 15, p. 235-242, 1895.
- DIE KOHLENSTAUBFEUERUNG, Schneider.—*Zeit. des Verbandes der Dampfkessel Ueberwachungs-Vereins*, vol. 18, p. 336, 1895.
- KOHLENSTAUBFEUERUNGEN, Schrey.—*Glaeser's Annalen fur Gewerbe und Bauwesen*, vol. 36, p. 213-219; discussion, p. 219-220, 1895. Paper read before the Verein deutscher Maschinen Ingenieure.
- KOHLENSTAUBFEUERUNGEN VON SCHWARTZKOPFF.—Oest. Zeitschrift für Berg und Huttenwesen, vol. 43, p. 187-188, 1895.
- DIE SCHWARTZKOPF'SCHE KOHLENSTAUBFEUERUNG, Schneider.—*Zeit. Verband Dampfkessel Ueberwach.*, Ver., vol. 18, p. 403, 1895.
- VERSUCHSERGEBNISSE MIT DER WEGNER'SCHEN KOHLENSTAUBFEUERUNG.—*Zeit. Verband Dampfkessel Ueberwach.*, Ver., vol. 18, p. 380, 1895.
- KOHLENSTAUBFEUERUNGEN.—*Zeit. des Vereins deutscher Ingenieure*, vol. 39, p. 1379-1382, 1895. Abstract in *Engineer (Lond.)*, vol. 81, p. 106, 1896. Gives historical sketch of the use of coal dust as fuel.
- CHAUFFAGE DES CHAUDIERES AU CHARBON PULVERISE (Systeme Baumert et Wegener).—*Revue Industrielle*, vol. 25, p. 62-63, 1894.
- APPAREIL FRIEDEBERG POUR BRULER LA POUSSIÈRE DE CHARBON, G. Lestang.—*Revue Industrielle*, vol. 25, p. 461-462, 1894.
- APPARATUS FOR BURNING COAL DUST (Friedeberg system).—*Industries and Iron*, vol. 17, p. 354, 1894.
- STAUBKOHLENFEUERUNG (EINRICHTUNG UND VERSUCHE IN DER INKRUSTATIONSFABRIK ZU PLOETZENSEE).—*Dampf*, vol. 11, p. 102, 1894.
- UEBER KOHLENSTAUBFEUERUNGEN.—*Dampf*, vol. 11, p. 509, 1894.
- NEUERE DAMPKESSEL KESSELFUERUNGEN.—*Dingler's Polytechnische Journal*, vol. 291, p. 241-247, 1894.
- UEBER KOHLENSTAUBFEUERUNGEN.—*Dingler's Polytechnische Journal*, vol. 292, p. 265-270, 1894.
- FRIEDEBERG APPARATUS FOR BURNING COAL DUST.—*Industries and Iron*, vol. 17, p. 405, 1894.
- DIE KOHLENSTAUBFEUERUNG PATENTS FRIEDEBERG, B. Kosmann.—*Berg u. Huttenmannische Zeitung*, vol. 53, p. 371-374, 1894.
- NEUERE KESSELFUERUNGEN.—*Dingler's Polytechnische Journal*, vol. 287, p. 108, 1893.
- KOHLENSTAUBFEUERUNG VON BAUMERT UND WEGENER.—*Dingler's Polytechnische Journal*, vol. 289, p. 23, 1893. Paragraph on use by the North German Lloyd Company.
- MELDRUM SELF-CONTAINED DUST-FUEL FURNACE, Wm. Boby.—Federated Institution of Mining Engineers, Trans., Vol. 3, p. 250-255, 1891-1892.

- STEAM BOILERS WITH FORCED BLAST: THE PERRET SYSTEM FOR BURNING DUST AND REJECTED FUELS, WITH NOTES ON TESTING BOILERS, Bryan Donkin.—Federated Institution of Mining Engineers, Trans., vol. 4, p. 154-166, 1892-1893. Discussion of papers by Wm. Boby and B. Donkin, p. 348-350.
- RAUCHLOSE KOHLENVERBRENNUNG (MITTELST STAUBKOHLE).—Mittheilungen aus dem Gebiete des Seewesens, vol. 21, p. 63, 1893.
- FOYERS DU SYSTEME DE MM. BAUMERT ET WEGENER POUR L'UTILISATION SOUS LES CHAUDIERES DE CHARBON PULVERISE.—Revue Universelle des Mines, vol. 24, p. 238-241, 1893.
- UEBER EINE NEUE FEUERUNG (PATENT KUDLICZ) ZUM VERBRENNEN VON FEINKOHLE, KOHLENLOESCHE, SCHLAMM KOHLE, KOKSKLEIN, BRAUKOHLENABFAELLEN UND DERGL. L. Glaser.—Glaser's Annalen fur Gewerbe und Bauwesen, vol. 33, p. 31-37, 1893.
- ON SOME APPLIANCES FOR THE UTILISATION OF REFUSE AND DUST FUEL, Walter G. McMillan.—Society of Arts Journal, vol. 34, p. 527-540; discussion p. 540-542, 1886. Various furnaces are described and the results of tests with Perret's boiler furnace are given.
- POWDERED ANTHRACITE AND GAS FUEL.—Engineering News, vol. 16, p. 314-315, 1896. Abstract from Report of Scranton, Board of Trade.
- PERRET'S FURNACE FOR DUST FUEL.—Iron Age, December 10, 1885, p. 35. ON THE CONVERSION OF HEAT INTO USEFUL WORK, William Anderson, Society of Arts Journal, vol. 33, p. 643-656, 1885. The author describes Crampton's system of coal-dust burning for a revolving puddling furnace, also the same system adapted to marine boilers.
- THE UTILISATION OF COAL DUST AS FUEL.—Engineering News, vol. 10, p. 163, 1883.
- COAL DUST FUEL.—Engineer (Lond.), vol. 43, p. 335-336, 1877. Gives results of experiments with Stevenson's apparatus.
- ON THE USE OF PULVERISED FUEL, B. F. Isherwood.—Engineering and Mining Journal, vol. 21, p. 12, 31, 57, 104, 129, 1876. An account of experiments made at South Boston with the Whelpley and Storer apparatus. In addition, the author gives a sketch of the history of pulverised coal burning, beginning with the English patent of J. S. Dawes in 1831.
- NOTES SUR LES DANGERS QUE PARAIT PRESENTER LA POUSSIÈRE DE HOUILLE DANS LES MINES, MÊME EN L'ABSENCE DE GRISON.—Annales des Mines, Mémoires, ser. 7, vol. 7, 176-179, 1875.
- ON THE COMBUSTION OF POWDERED FUEL IN REVOLVING FURNACES AND ITS APPLICATION TO HEATING AND PUDDLING FURNACES, T. R. Crampton.—Iron and Steel Institute Journal, 1873, p. 91-101; discussion p. 101-107.
- ON THE USE OF PULVERISED FUEL, Lieut. C. E. Dutton.—Franklin Institute Journal, vol. 81, p. 377; vol. 92, p. 17, 1871. Whelpley and Storer process.
- FOUR CRAMPTON, M. Lavallee.—Société des Ingénieurs Civils de France, Mémoires, 1875, p. 266-272; discussion p. 272-278.

BOOKS AND PAMPHLETS.

- BARR, WILLIAM M.—A Practical Treatise on the Combustion of Coal, including descriptions of various mechanical devices for the economic generation of heat by the combustion of fuel, whether solid, liquid or gaseous. Indianapolis, John Bros., 1879, Chapter 14—Coal dust fuel. An account of experiments made by the U.S. Government in 1876. Comparative economy of powdered fuel as compared with ordinary coal. Stevenson's apparatus for burning coal dust.
- CLARK, D. KINNEAR, editor.—Fuel: its combustion and economy, consisting of abridgments of "Treatise on the Combustion of Coal and Prevention of Smoke," by C. W. Williams, and "The Economy of Fuel," by T. Symes and Prideaux, with extensive additions on recent practice in the combustion and economy of fuel, coal, coke, wood, peat, petroleum, etc. Lend, Crosby, Lockwood; New York, Van Nostrand, 1879. Chapter 25—Powdered Fuel.
- DAMOUR, EMILIO AND QUENEAU, A.L.J. Industrial Furnaces.—New York, Engineering and Mining Journal, 1906, p. 275-286. Contains list of U.S. Patents covering the stoking of powdered fuel to May 10, 1904.
- FOWLER, WILLIAM H.—Steam Boilers and Supplementary Appliances. Manchester, Scientific Pub Co., p. 491-492, paragraph on dust fuel stokers.

- GROVES, CHARLES EDWARD, AND THORP, WILLIAM.—*Chemical Technology, vol. 1. Fuel and its Applications.* By E. J. Mills and F. R. Rowan. Philadelphia, Bladiston, 1889, p. 364, 664.
- HOFMAN, H. O.—*General Metallurgy.* New York, McGraw-Hill Book Co., 1913, p. 183-189. Mention is made of the early attempts to utilise coal dust as fuel, beginning with Niepce in 1818. A list of references is given.
- HUTTON, FREDERICK REMSEN.—*The Mechanical Engineering of Steam Power Plants.* Ed. 3. New York, Wiley, 1908. Chapter 9—Firing boilers with gas or liquid hydrocarbon, or with pulverised fuel.
- KENT, WM.—*Steam Boiler Economy.* New York, Wiley, 1901, p. 183.
- PEUTSCH, ALBERT.—*Gas and Coal Dust Firing; a critical review of the various appliances patented in Germany for this purpose since 1885;* translated by Charles Salter, London, 1901.
- THURSTON, R. H.—*A Manual of Steam Boilers, their design, construction and operation.* New York, Wiley, 1888, p. 164-165. Paragraph on pulverised coal.
- TURIN, ANDRE.—*Les Foyers de chaudières.* Paris, Dunod & Pinat, 1913, p. 156-161.
- U.S. STEAM ENGINEERING BUREAU (NAVY DEPARTMENT).—Annual Report, 1876. Washington, Govt., 1876. Experiments were made under the direction of B. F. Isherwood with a horizontal fire-tube boiler at East Boston, Mass., to test the process of Whelpley and Storer for effecting the combustion of coal dust. The apparatus for grinding the coal was the only part of the process which was patented. The coal dust was blown upon a bed of ignited lump coal. Tables are given showing the comparative economy of burning lump coal alone, or lump coal with coal dust. It was found that the use of powdered fuel was more expensive on account of the cost of pulverisation.

Herrington, C. F.—Powdered Coal as a Fuel. The only book as yet published exclusively dealing with this subject. D. Van Nostrand. New York.

(Second Edition—1920).

BIBLIOGRAPHY OF ARTICLES ON POWDERED COAL.

(Taken from the Authors Iron and Steel Institute Paper, 1919).

- ANDERSON, J.—“Pulverised Fuel in a Milwaukee Power Plant.” 1918. *Railway Review*, October 26, vol. lxiii, pp. 606-607.
- ATKINSON, J. S.—“The Application of Pulverised Fuel to Metallurgical Furnaces and Steam Boilers.” *Machinery Market*, August 30, 1918.
- BARNHURST, H. G.—“General Utilisation of Pulverised Coal.” December 1917.
- “Pulverised Coal and its Future.” *General Electric Review*, February 1918.
- “General Utilisation of Pulverised Coal.” 1918. *Chemical Engineering and Mining Review*, March 5, vol. x, pp. 174-177.
- “Pulverised Coal as a Fuel.” 1918. *Machinery*, June 19, vol. xxiv, p. 901.
- Abstract of paper read before Cleveland Engineering Society.
- “Powdered-Fuel Installation Service, 10-250 Horse-power O’Brien Boilers.” *Journal of American Society of Mechanical Engineers*, October 1916.
- “Powdered Fuel in Open-Hearth and Small Heating Furnaces.” *Iron and Coal Trades Review*, April 12, 1918.
- BEAN, W. R.—“Pulverised Coal for Air Furnaces.” *Iron Trade Review*, September 27, 1917.
- BEISTLE, C. P.—“Hazards in the storage of Pulverised Coal.”
- BENDER, LOUIS V.—“Coal-Dust Fired Reverberatories at Washoe Reduction Works.” *Bulletin of the American Institute of Mining Engineers*, January 1915, p. 73; and May 1915, p. 1174.
- BROWNE, DAVID H.—“Coal-Dust Fired Reverberatory Furnaces of Canadian Copper Company.” *Bulletin of the American Institute of Mining Engineers*, January 1915, p. 49.
- “Recent Improvements and Additions to the Smelting Plant of the Canadian Copper Company.” 8 pp. 1912.

- BROWNE, DAVID H.—“Firing of Reverberatory Furnaces with Pulverised Coal.” *Transactions of the Canadian Mining Institute*, vol. xv. p. 115.
- CARACRISTI, V. Z.—“Utilisation of Waste and Undeveloped Fuels in Pulverised Form.” Parts I. and II. *General Electric Review*, September 1917.
- “The Use of Pulverised Fuel for Locomotive Operation.” *General Electric Review*, November 1917.
- CARPENTER, R. C.—“Symposium on Powdered Fuel,” No. 1431A, “Pulverised Coal Burning in the Cement Industry.” *The American Society of Mechanical Engineers*, June 1914. Containing papers by William Dalton and W. S. Quigley. No. 1431B, “An Installation for Powdered-Coal Fuel in Industrial Furnaces,” F. R. Low. No. 1431C, “Pulverised Coal for Steam-Making.” Discussion of the above papers by J. L. Agnew, W. P. Barba, H. G. Barnhurst, John V. Culliney, W. R. Dunn, William A. Evans, Edward J. Kelley, and A. W. Raymond.
- COFFIN, F. P.—“The Use of Low-Grade Universal Fuels and the Status of Powdered Coal.” *General Electric Review*, August 1917.
- “The Extent of the Use of Pulverised Fuel in the Industries and its Possibilities in the War.” May 1918.
- COLLINS, H. R.—“Use of Coal in Pulverised Form.” 1918. *Colliery Guardian*, May 10, vol. cxv. pp. 945-946. Paper presented to American Institute of Mining Engineers.
- “First Pulverised-Coal Installation in Western Canada.” 1918. *Mining and Engineering Record*, September 30, vol. xxiii. pp. 117-119.
- “Use of Coal in Pulverised Form.” 1918. *Colliery Guardian*, September 13, p. 557.
- COLLINS, H. R., and JOSEPH HARRINGTON.—“Pulverised Fuel in a Power Plant on the Missouri, Kansas, and Texas Railway.” *General Electric Review*, October 1917.
- CUNLIFFE, J.—“Pulverised Coal for Industrial Purposes.” 1918. *Coal Age*, May 25, pp. 963-967.
- “Pulverising Coal.” 1918. *Engineering and Cement World*, November 15, vol. xiii. pp. 56-57.
- “The Growing Use of Pulverised Coal.” 1918. *Contract Record*, December 11, vol. xxxii. pp. 988-989.
- “Pulverised Coal for Industrial Purposes.” *Mechanical World*, April 27, 1918.
- DURAND, F. W.—“Progress and Outlook in Prime Movers.” *Electrical World*, January 6, 1917. Professor Neutch Engineering, Leland University.
- FULLER, J. W.—“Pulverised Coal for Open-Hearth Furnaces.” *Iron Trade Review*, November 2, 1916.
- HACHTMANN, A. P.—“Pulverised Coal versus Producer-Gas as a Fuel for Nodulising Fine Iron Ore in the Rotary Kiln.” *The Chemical Engineer*, May 1909.
- HARRINGTON, J.—“Powdered Coal as a Fuel in Malleable Shops.” *The Foundry*, September 1916, October 1916, December 1916, January 1917.
- “The Use of Powdered Coal as a Fuel.” *Journal of American Society of Mechanical Engineers*, October 1916.
- HARRISON, S. H.—“Pulverised Coal: Its Preparation and Use in Industrial Furnaces.” *Engineering Magazine*, February 1916.
- HERRINGTON, C. F.—“Powdered Coal for Heating Furnaces.” *The Iron Age*, November 5, 1914.
- “Substituting Powdered Coal for other Fuels.” 1918. *Blast-Furnace and Steel Plant*, July, vol. vi. pp. 285-288.
- “Powdered Coal as a Fuel.” D. Van Nostrand Company, New York. 212 pp. \$3.00. 1918. *National Engineer*, August, vol. xxii. p. 390. The only book as yet published on this subject.
- “New System of Burning Powdered Coal.” *Engineering News*, May 27, 1915.
- “Comparison of the Economy of Powdered Coal, Oil and Water Gas for Heating Furnaces.” *Engineering News*, December 10, 1914.
- GADD, C. J.—“The Use of Powdered Coal in Metallurgical Processes: A Discussion of the Engineering Principles Involved.” *Journal of the Franklin Institute*, September 1916, p. 323.
- “Utilising Powdered Coal at Lebanon, Pa.” *The Iron Age*.
- JAMES, H.—“Conservation of Fuel.” 1918. *Power House*, May, pp. 127-128.

- KINYON, ALONZO.—“ Powdered Coal Equipment Company, Chicago.” *The Iron Age*, February 1, 1917.
- KNOWLES, E. R.—“ Pulverised Fuel.” *Steam*, October, vol. xxii. pp. 96-102.
- “ Pulverised Fuel.” 1918. *Steam*, November, vol. xxii. pp. 128-133.
- KUZELL, C. R.—“ Coal-Dust Firing in Reverberatory Furnaces.” *Engineering and Mining Journal*, February 12, 1916.
- LAIST, FREDERICK.—“ Changes in Smelting Practice of Anaconda Copper Mining Company.” *Engineering and Mining Journal*, October 7, 1916.
- LONGNECKER, CHAS.—“ Diversified Application of Powdered Coal.” 1918. *Iron Age*, September 12, pp. 619-623.
- LOD, J.—“ The Use of Pulverised Coal in Metallurgical Furnaces.” *Proceedings of the Engineers’ Society of Western Pennsylvania*, October 1913.
- MATHEWSON, E. P.—“ Anaconda Coal Pulveriser Plant.” *Mining Journal*, July 10, 1915.
- MILLER, S.—“ Report on Pulverised Fuel by U.S. Fuel and Fuel-Handling Committee of Nava Consulting Board.” *Journal of American Society of Mechanical Engineers*, May 1918.
- MUHLFELD, JOHN E.—“ Pulverised Fuel for Locomotives.” *Journal of the American Society of Mechanical Engineers*, December 1916.
- NAKAYA, S., and J. R. BLAKESLEE.—“ The Fushun Colliery and Power Plants of the South Manchuria Railway.” *General Electric Review*, September 1917.
- PERKINS, F. C.—“ Pulverised-Fuel Combustion.” 1918. *Power House*. September, p. 249.
- RIOE, C. T.—“ Use of Powdered Coal at the Bunker Hill and Sullivan Smelting and Refining Plant.” *Engineering and Mining Journal*, July 20, 1918.
- ROBINSON, J. G.—“ Perfectionnements dans l’emploi de combustible pulvérisé dans les foyers de générateurs de vapeur.” 1918. *Bulletin Officiel de la Propriété Industrielle et Commerciale*, No. 1774, p. 7.
- SANTMYER, W. J., Abstract of article by.—“ Powdered Coal.” *Electrical Review*, April 18, 1918.
- “ The Use of Coal in Pulverised Form.” 1918. *Bulletin of the American Institute of Mining Engineers*, No. 143, November, pp. 1678-1684.
- TRANTSCHOLD, REGINALD.—“ Burning Pulverised Coal at the Mine.” *Coal Age*, July 15, 1916.
- WILCOX, W. G.—“ Use of Powdered Coal.” 1918. *Mining and Scientific Press*, June 22, vol. cxvi. pp. 849-853.
- “ The Possibilities of Powdered Coal.” 1918. *Scientific American Supplement*, July 27, pp. 62-64.
- “ The Use of Powdered Coal.” 1918. *Western Engineering*, July, pp. 267-271.
- “ The Possibilities of Powdered Coal, as shown by its Combustion Characteristics.” 1918. *Chemical and Metallurgical Engineering*, No. 1, July 1, vol. xix. pp. 35-40.
- “ Control of Combustible and Air in Burning Powdered Coal.” 1918. *Compressed Air Magazine*, August, vol. xxiii. pp. 8839-8841.
- “ Possibilities of Powdered Coal as shown by its Combustion Characteristics.” 1918. *Steam*, September, vol. xxii. pp. 70-75.
- “ Control of Fuel and Air in Burning Powdered Coal.” 1918. *Colliery Guardian*, October 18, vol. cxvi. pp. 808-809.
- “ Powdered Coal an Ideal War-time Fuel.” *Iron and Coal Trades Review*, October 4, 1918.
- WILSON, E. B.—“ Firing with Coal Dust.” *The Colliery Engineer*, October 1915.
- “ Powdered-Coal Preparation and Firing in Germany.” *Journal of American Society of Mechanical Engineers*, November 1915.

MISCELLANEOUS.

- “ New Iron Mill Equipped to assure Low Costs.” St. Louis Screw Company Powdered-Coal Plant. *The Iron Age*, July 8, 1915.
- “ Regenerators for Open-Hearth Powdered-Coal Fired Furnaces.” J. E. Bell Patent. *The Iron Age*, May 18, 1916.
- “ Powdered-Coal Burning at Works of Standard Steel Caf Company, Middletown, Pa.” *The Iron Age*, July 20, 1916.

- "Powdered Coal for Large Furnaces." Upson Nut Company. *Iron Trade Review*, April 26, 1917.
- "Utilising the Waste from Coal Mines in the Pacific North-West." *Metallurgical and Chemical Engineering*, May 15, 1917.
- "Pulverized-Coal Plant in Anaconda." *Metallurgical and Chemical Engineering*, May 1915.
- "Pulverised Coal Plant for the Santa Fé Railway. *Railway Age Gazette*, February 9, 1917.
- "Powdered Coal." Reports of Commission to International Railway Fuel Association. 1915, 1916, 1917 Conventions.
- Railway Fire Protection Association, St. Louis, October 2, 4. *Railway Age Gazette*, October 19, 1917.
- "Pulverised Coal on American Locomotives." *Engineer*, August 23 and 30, 1918.
- "Pulverised Fuel Locomotive." Great Central Railway. *Engineer*, April 25, 1919.

ADDITIONAL BIBLIOGRAPHY

to November, 1920.

Compiled by "Engineering Societies Library" New York.

1919.

- Ref. 157. Apparatus for burning powdered coal. 1919. (In *Eng. & Indust. Manage.*, v. 2, p. 325.) Describes Grindle system of burning powdered coal, which has a feed screw which runs through wide section of hopper, thus preventing packing of coal.
- ,, 158. ARROWOOD, M. W. Develop firing system for air furnaces. 1919. (In *Foundry*, v. 47, pp. 677-79.) Series of tests were made at Meadville, Pa., with air furnaces using a specially designed burner for pulverized coal for malleable iron melting also for annealing. Economies indicated are discussed.
- ,, 159. ATKINSON, J. S. The combustion of powdered fuel. 1919. (In *Electrician*, v. 82, pp. 730-32.) Detailed account of Holbeck system. Importance of proper burner. Plans.
- ,, 160. ATKINSON, J. S. Powdered fuel for firing metallurgical furnaces and steam boilers. 1919. (In *Iron and Coal Trades Rev.*, v. 98, pp. 651-52. *West of Scotland Iron and Steel Inst. Jnl.*, v. 27, pp. 44-57.) Drying, pulverizing to proper degree, mixing with air before combustion. Plans.
- ,, 161. BARNHURST, H. G. Pulverized coal and its bearing on the fuel situation. 1919. (In *Manuf. Rec.*, v. 75, pp. 107-8.) Chiefly in the cost of preparing coal in plants of various capacities.
- ,, 162. BARNHURST, H. G. Pulverized coal and its bearing on the fuel situation. 1919. (In *Amer. Fertilizer*, v. 50, pp. 48-49.) On Cost of pulverized coal equipment per boiler per rated boiler horsepower.
- ,, 163. BOUSQUET, M. Le chauffage industriel par le charbon pulvérisé. 1919. (In *Nature*, année 47, Sem. 2, pp. 318-20.) Industrial firing with powdered coal. On the efficiency of powdered coal, costs description of Fuller and Holbeck systems, &c. A summary of this article is found in *Technical Rev.*, v. 6, p. 13.

- Ref 164. Burning powdered coal successfully. 1919. (In *Power*, v. 49, pp. 90-1.)
 Tells of an experiment of the Puget Sound Traction, Light and Power Co., for which test a 300 h.p. water-tube boiler was equipped with a Dutch oven; the powdered coal was delivered to an inclosed bunker by bucket elevators. From the bunker the coal was fed by air pressure through pipes and a locally designed burner to the furnace. Some data on their new building and its equipment and results obtained from tests. 4 photos.
- ,, 165. Burning pulverized coal in a sheet mill. 1919. (In *Iron Age*, v. 104, pp. 1167-72.)
 Newport Rolling Mill Co., of Newport, Ky., replaces natural gas with powdered coal. It is carried by compressed air 2,500 ft. in 4-in. pipe to bins at furnaces. Description of the Quigley systems with plans and illustrations. Shows amount of coal used per ton of various kinds of products.
- ,, 167. DELANEY, C. H.
 Use of pulverized California coal. 1919. (In *Jnl. Elect.*, v. 42, pp. 357-59. Same in *Nat. Engr.*, v. 23, pp. 278-79.)
 A consideration of pulverized California coal as a substitute for fuel oil. First costs and operating expenses when using each compared.
- ,, 168. DAMOUR, E.
 Progres realises pendant la guerre dans l'utilisation des combustibles. 1919. (In *Industrie Electrique*, Year 28, Jan. 10, pp. 5-7.)
 From extensive account in *Chemie et Industrie*.
 Progress realized during the war in the utilization of fuels. On the gasification and pulverization of fuels.
- ,, 169. DICK, W. J.
 Pulverized fuel; its use and possibilities. 1919. Ottawa, Canada, Commission of Conservation. p. 57.
 General fuel situation in Canada. Pulverised fuel-history.
 Pulverized coal in boiler plants, in cement industry, in metallurgical industries, for power purposes, on railroads. Under these heads are described the most important examples. Detailed tables give results of locomotive tests. Plans and illustrations.
- ,, 170. Economia del combustibile per impiego di carbone polverizzato. 1919.
 (In *Rivista Tecnica d'Elettricina*. 1919, pp. 11-16.)
 Saving fuel by using pulverized coal.
- ,, 172. FITCH, W. H.
 Pulverized coal in open-hearth practice. 1919. (In *Iron Age*, v. 104, pp. 1323-1328.)
 A review of the experience of 18 American steel plants. Feeder and burner mechanism. Proper furnace design. Basic process only employed. Various qualities of coal used, foot grade if other not obtainable. 500 to 700 lbs. of coal used per ton of product.
- ,, 173. For burning powdered coal. 1919. (In *Iron Age*, v. 104, p. 444.)
 A description of the Grindle system with drawing. Especially designed device to prevent packing. Control of both coal and air well provided for.
- ,, 174. FOSTER, J. T.
 Pulverized coal burners versus stokers. 1919. (In *Elect. Wld.*, v. 73, pp. 474-5.)
 Chart shows maximum amount that can be paid for pulverized coal to make it comparable with a given stoker coal. Freight charges on low grade and high grade fuel.
- ,, 175. GOODWIN, C. J.
 Waste heat boilers and pulverized fuel in chemical factories. 1919.
 (In *Chem. Industry*, v. 38, pp. 213T-210T. Discussion 220T-222T.)
 Descriptions of several plants in England. Plans.

Ref. 176. GRINDLE, A. J.

Powdered coal for the small foundry. 1919. (In *Foundry*, v. 47, pp. 679-80.)

Author shows that steel is being melted with 450-600 lbs. of powdered coal per ton of charge, and that 15 malleable foundries using powdered coal for annealing have a fuel ratio of from 500-700 lbs. of coal per ton of castings. Analyses of coals which have proved satisfactory for use in powdered form.

.. 177. HARRISON, N. C.

Pulverized coal. 1919. (In *Mech. Engn.*, v. 41, pp. 645-49, excerpts in *Power*, v. 50, pp. 287-91; *National Engr.*, v. 23, pp. 617-21. Also issued as pamphlet.)

Tells of the use of pulverized coal in the cement, steel and copper smelting industries. The open hearth steel plant of the American Manufacturing Co. of Lebanon, Penna., uses pulverized coal and its apparatus is described. Shows advantages of using pulverized coal instead of producer gas in open hearth furnaces. Cost of the two fuels compared.

.. 178. HARRISON, N. C.

Using pulverized coal as a boiler fuel. 1919. (In *Power House*, v. 12, pp. 392-396.)

General survey. Definition of pulverized coal. Description of coal-pulverizing plant. Costs of pulverizing coal with table. Use in open-hearth and metallurgical furnaces. Boilers. Pulverized coal vs. mechanical stokers.

.. 188. HERINGTON, C. F.

Pulverized coal as the reconstruction fuel for all industrial heating operations. 1919. (In *Iron and Steel of Canad.*, v. 2, pp. 77-83.)

Equivalent prices of powdered coal and other fuel. Detailed description and plans of powdered-coal plant.

.. 189. HERINGTON, C. F.

Pulverized coal in Canadian Steel Plant. 1919. (In *Iron Age*, v. 103, pp. 1065-1069.)

Air distributing system supplies powdered fuel for boilers and furnaces. Waste heat boilers a feature. Holbeck system is used and has proved both satisfactory and economical. This article describes and illustrates the various applications of powdered coal in this plant near Montreal. Tests of the coal gave good results as shown.

.. 190. High efficiency of powdered coal as fuel. 1919.

(In *Coal Tr. Jnl.*, v. 50, pp. 1018-1019.)

Description of a controller and burner. Comparison with other fuel.

.. 191. Instructions for safe use of pulverized fuel. 1919.

(In *Engr.*, v. 127, pp. 398-99.)

The rules were prepared by Pulverized Fuel Equipment Co. of N.Y.

Pt. I. Rules for fuel preparing, storing and distributing equipment.

Pt. II. Rules for fuel feeding, burning and furnace equipment.

.. 192. KIMBER, H. A.

Powdered coal advance and development. 1919. (In *Blast Furnace and Steel Plant*, v. 7, pp. 67-68.)

Powdered coal for raising steam. Apparatus for distribution and control of the coal. List of new pulverized coal installations in 1918.

.. 193. LASSEUR, E.

L'emploi du charbon pulvérisé sur les locomotives. 1919. (In *Genie Civil*, v. 74, pp. 345-49.)

Use of pulverized coal in locomotives. Present development particularly as practiced by the Locomotive Pulverized Fuel Co. of N.Y.

.. 194. Locomotive chauffée au charbon pulvérisé du Great Central Railway. (Angleterre.) 1919. (In *Genie Civil*, v. 74, pp. 504-06.)

Locomotive fired with pulverized coal on the Great Central Railway, England. General description of apparatus, with drawings. Rules for caring for the coal by a New York Company.

- Ref. 195. LONGENECKER, CHAS.
 Using pulverized coal for annealing. 1919. (In *Foundry*, v. 47, pp. 680-81.)
 Gives data on an installation of powdered coal burning equipment on malleable iron annealing furnaces which shows a cost of \$2625 where using powdered coal against \$4900 for doing same amount of annealing with natural gas and \$8400, when using fuel oil. Another foundry showed 48 per cent. saving in amount of coal used when in powdered form.
- ,, 196. MATHEWSON, E. P. and WOTHERSPOON, W. L.
 Application of pulverized coal in blast furnaces. 1919. (In *Canad. Min. Inst. Bull.*, v. 87, pp. 737-60; abstract *Engng. & Mining Jnl.*, v. 108, pp. 274-76.)
 Tells of experiments in various plants notably Tennessee Copper Co. and International Nickel Co. smelters. The coal is blown in through the tuyeres. Plans show how it was done. Table gives estimated costs of pulverized coal plants of various capacities. Authors think that pulverized coal will make considerable savings.
- ,, 197. MUHLFELD, J. E.
 Pulverized coal in locomotive and marine service. 1919. (In *Mech. Engng.*, v. 41, pp. 752-54.)
 Brazilian coal not easily used on grates. Only by adopting the pulverized coal system can it be economically used. This paper describes the system as installed on hundreds of locomotives in Brazil. Tables of tests on locomotives in Brazil also in U.S.
- ,, 198. ODELL, W. H.
 The use of pulverized coal. 1919. (In *Steam*, v. 23, pp. 93-95.)
 Description of Fuller-Lehigh pulverizer mill. Plans.
- ,, 199. ODELL, W. H.
 The use of pulverized coal. 1919. (In *Steam*, v. 23, pp. 33-5, 63-5.)
 Description of the Raymond system of pulverizing coal and air separation. Plans.
- , 200. Powdered coal and its equipment. 1919. (In *Power Plant Engng.*, v. 23, pp. 1006-09.)
- , 201. Powdered coal as a substitute for fuel oil. 1919. (In *Min. & Sci. Pr.*, v. 118, pp. 235-36.)
 Description of an experimental plant using the Buell-Santmyer system.
- , 203. Powdered fuel for Hammersmith. 1919. (In *Elect. Times*, v. 55, pp. 168-69.)
 Illustrated description of Holbeck system for using powdered fuel under boilers.
- , 204. Progress in utilizing pulverized coal. 1919. (In *Coal Age*, v. 15, pp. 992-95.)
 This is confined to locomotive practice. Gives summary of reports of railroads in No. and So. America. Tables. Results indicate that pulverized coal will increasingly be used on locomotives.
- , 205. Puget Sound Traction, Light and Power Company's pulverized coal plant. 1919. (In *Stone and Webster Jnl.*, v. 25, p. 96-109.)
 Results of tests and availability of culm dump of 225,000 tons led to decision to use pulverized coal in plant.
- , 206. Pulverized coal. 1919. (In *Power Plant Engng.*, v. 23, pp. 678-81.)
- , 207. Pulverized coal, in blast furnaces. 1919. (In *Iron and Coal Trds. Rev.*, v. 99, pp. 204-05.)
- , 208. Pulverized coal in boiler and furnace. 1919. (In *Iron Age*, v. 104, pp. 709-10.)
 A comparison with producer gas as fuel for open-hearth furnaces. Advantages and disadvantages discussed.

- Ref. 209. Pulverized fuel for the railways. 1919. (In *Power*, v. 49, p. 997.)
 Summaries of three tests. Efficiency, costs. Some troubles with pulverized coal.
- ,, 210. Pulverised fuel for the railways. 1919. (In *Power*, v. 50, pp. 516-17.)
 This refers to article in *Power*, v. 49, p. 997. The present writer explains away the troubles caused by using pulverized coal that are spoken of in the first case.
- ,, 211. Pulverised fuel locomotive. 1919. (In *Engr.*, v. 127, pp. 400-02.)
 Great Central Railway of England experimented with pulverized fuel not long ago. General description of the engine and detailed description of burning apparatus. Fire box plan and large detailed plans of whole burning apparatus.
- ,, 212. RENKIN, W. O.
 A review on the use of powdered coal. 1919. (In *Blast Furnace and St. Plant*, v. 7, pp. 114-16, 119. Also in *Amer. Drop Forger*, v. 5, pp. 22-25.)
 Graph showing comparative value and advantages of different fuel. Comparison of installation and operating costs of producer gas, natural gas and hand-fired coal. Early uses of powdered coal.
- ,, 213. RENKIN, W. O. and LONGENECKER, C.
 Using powdered coal as a forge shop fuel. 1919. (In *Amer. Drop Forger*, v. 5, pp. 283-90.)
- ,, 214. REVEILLAC, M.
 L'emploi du charbon pulverize. 1919. (In *Bull et comptes rendus mensuels de la Societe de l'Industrie Minerale*, v. 16, p. 347-65.)
 On the economic side of burning pulverized coal. Holbrook system.
- ,, 215. SCHEFFLER, F. A. and BARNHURST, H. G.
 Pulverized coal for stationary boilers. 1919. (In *Mech. Engng.*, v. 41, pp. 650-2. Discussion 652-53. Same in *Elect. Rev.*, v. 75, pp. 817-21. Abstract in *Power*, v. 50, pp. 291-96 and in *Iron Age*, v. 104, p. 710.)
 Comparison of stoker and pulverised fuel plants with respect to reliability cost, adaptability and efficiency.
- ,, 216. WELLES, E. R. and JACOBI, W. H.
 Pulverized coal as a fuel for boilers. 1919. (In *Mech. Engng.*, v. 41, pp. 744-49. Abstracts in *Power*, v. 50, pp. 520-21; *Elect. Wld.* v. 74, p. 742; *Concrete*, v. 15, sup. p. 77. *Steam*, v. 26, pp. 63-68 and continuation)
 General study of its characteristics and the operating conditions met with in its commercial applications. Nature of flame, types of burners, design of furnace for 500 h.p. boiler.
- ,, 217. WILCOX, W. G.
 Characteristics of powdered coal. 1919. (In *Brick and Clay Rec.*, v. 54, pp. 127-31.)
 Practical advice on securing maximum efficiency when using powdered coal.
- ,, 218. WILCOX, W. G.
 Success in combustion of powdered coal. 1919. (In *Black Diamond*, v. 62, pp. 328-29.)
 Considers the rate of combustion and importance of thoroughly mixing the coal and air.
 1920.
- ,, 219. Aero-pulverizer. 1920. (In *Engr.*, v. 129, pp. 306-07.)
 Description of machine used in England which reduces coal to proper fineness for furnaces and feeds it into furnaces.
- ,, 220. ANDERSON, JOHN.
 Pulverized coal for fuel makes good saving in Milwaukee. 1920.
 (In *Elect Ry. Jnl.*, v. 55, pp. 473-76. Discussion 476-77.)
 "Ease with which fuel feed and draft are controlled, ability to take and drop heavy overloads quickly without waste, thorough combustion and uniformly high efficiency are chief advantages of pulverized coal."

- Ref. 221. ANDERSON, JOHN.
 Tests of pulverized fuel equipment. 1920. (In *Combustion*, v. 2, pp. 25-27; v. 3, pp. 17-21.)
 Tabulated results of tests at Oneida Street. Plant of Milwaukee Elec. Ry and Light Co. Description of apparatus, instruments, coal, operating conditions and boiler iron used in the tests. Plans.
- ,, 222. ANDERSON, JOHN.
 Pulverized coal under central-station boilers. 1920. (In *Power*, v. 51, pp. 336-339.)
 Equipment required, method of applying and facts concerning operation. The chief merits of powdered coal are high efficiency and flexibility to meet varying demands.
- ,, 223. ANDERSON, JOHN.
 Pulverised coal for central station boilers. 1920. (In *Combustion*, v. 2, pp. 24-26.)
 The author is chief engineer of the power plants of the Milwaukee Elec. Ry. and Light Co. which has used pulverised coal on a very large scale for two years besides making exhaustive tests. Topics treated are: Special requirements for pulverised coal, drying the coal, cost range for preparing, securing dependable operation, efficient combustion, furnace limitations, efficiency, plant size limitations, explosions.
- ,, 224. ANDERSON, JOHN.
 Pulverized coal in central stations. 1920. (In *Elect Wld.*, v. 75, pp. 589-91; *Steam*, v. 25, pp. 100-01.)
 Tests of its uses in furnaces showed 80 per cent. efficiency. No clinkering of coal, no cleaning of fires, no smoke. Load fluctuations easily handled.
- ,, 225. BARNHURST, H. C.
 Pulverized coal and its future. 1920. (In *Universal Engineer*, v. 32, pp. 49-51; *Enggn. Wld.*, v. 17, pp. 17-9.)
 These two articles are not identical but nearly so. They give reasons for the earlier unsuccessful attempts to use pulverized coal. Advantages in using it. Equipment and cost of preparation. Method of preparation, &c.
- ,, 226. BARNHURST, H. F.
 Pulverized coal for stationary boilers. 1920. (In *Combustion*, v. 2, pp. 18-20.)
 Remarks on the advantages of pulverized coal speaking in particular of cleanliness, ease of control and completeness of combustion.
- ,, 227. BUELL, R. N.
 Economic use of pulverized brown coal. 1920. (In *Chem. Engng. and Min Rev.*, v. 12, pp. 225-47.)
 In Australia brown coal is so poor that it has been little used for industrial purposes. It can be best burned in pulverized form. This article shows some of the advantages of pulverized coal and of its use in various industries and particularly in metallurgy.
- ,, 228. Carbon pulverized para calderas fijas. 1920. (In *Sociedad de Fomento Fabril Boletin*, Ano 37, pp. 342-48.)
 Pulverized coal for stationary boilers. Costs of equipment and costs of preparing the coal. General considerations. Plans.
- ,, 229. Le chauffage industriel par le charbon pulvérisé. 1920. (In *Industrie électrique*, Année 29, pp. 236-37.)
 Industrial firing with pulverized coal. Short account of Fuller and Holbeck systems. Use on railroads. Aero-pulverizer, &c.
- ,, 230. COLE, A. C.
 Operating by powdered coal to save fuel. 1920. (In *Blast Furnace and Steel Plant*, v. 8, pp. 417-18.)
 "Giving the operation of a powdered coal plant and demonstrating the possibility of reducing the cost of operation by its use as a fuel including a description of equipment."

- Ref. 231. CORBET, DARRAH.
 Saw-mill refuse, powdered coal, and oil fuels. 1920. (In *Jnl. A.I.M.E.*, v. 39, pp. 715-32.)
 PP. 726-29. On powdered coal. Tells of equipment and experience of various firms.
- , 232. CROSS, B. J.
 Distributing pulverized coal to small plants. 1920. (In *Coal Age*, v. 17, pp. 635-37.)
 "Using pulverized coal from a central plant is getting to be a common practice in West. Pulverized sub-bituminous coal must be kept dry and air so far as possible excluded if the fuel is to be handled safely.
- , 233. DELANEY, C. H.
 Oil and powdered fuel for central stations. 1920. (In *Elect. Wld.*, v. 75, pp. 128-129.)
 Far West a pioneer in the use of both. Combustion of powdered coal will develop around mines. Mexican oil on Atlantic seaboard.
- , 234. DICK, W. J.
 The possibilities of pulverized fuel. 1920. (In *Power House*, v. 13, pp. 116-19.)
 The Commission of Conservation has paid considerable attention to the possibilities of utilizing Canada's low grade fuels and the report on pulverized fuel, of which this an abstract, points out one successful method.
 Use in boiler plants. The Bettington boiler used account of same. Some tests made are recorded in tables.
- , 235. Falcon Steel Co. operate sheet mill. Modern plant uses powdered coal fuel. 1920. (In *Blast Furnace and Steel Plant*, v. 8, pp. 274-80.)
 The last three pages of this article describe the fuel system with plan.
- , 236. Four day test on Oneida Street boilers burning pulverized coal. 1920 (In *Power*, v. 51, pp. 354-57. See also *Power Plant Engng.*, v. 24, pp. 313-21.)
 Apparatus and instruments. Kind of coal used in test. Operating condition.
 Analyses of losses:—
 Table 1. Test of five 468 h.p. boilers. Figures about this test given under 54 different headings.
 Table 2. Test on fuel pulverizing equipment. 54 different facts given here.
 Table 3. Summary of results-energy per ton of coal, cost of fuel preparation efficiencies.
 Table 4. Comparative results with pulverized fuel and under fed stoker per ton of coal burned.
 (See pages 61-67 of this report).
- , 237. FOURNICK, M.
 Le chauffage industrielle par le charbon pulvérisé. 1920. (In *Rec. Génér. des Sciences*, Année 31, pp. 112-21.)
 Industrial use of pulverized coal. Considers use in metallurgical furnaces. Describes Fuller and Holbeck systems. The aero-pulverizer—it pulverizes and feeds its product to the furnace. Use on railways. Plans.
- , 238. GAFFNEY, J. B.
 United States Nitrate Plant No. 2. 1920. (In *Cement, Mill and Quarry*, v. 16, pp. 15-20.)
 Pulverized coal was used in lime kilns 8 ft. in diameter and 125 ft. long. An account of the work done by the coal pulverizing machines, plans of the equipment showing many details and full description of all apparatus connected with the firing.

- Ref. 239. HARVEY, L. C.
 New pulverized coal equipments for railway locomotives. 1920. (In *Railway Engr.*, v. 41, pp. 303-07.)
 An account of the development of pulverized fuel for locomotives in America, Italy, and the Netherlands. I. Lehigh Valley R.R. results—many figures given. Saving made. II. Developments in Italy. Description of equipment to be used. III. Pulverized peat-fired locomotives in Sweden. Plan. Tests.
- ,, 240. HARVEY, L. C. and NOBLE, E. E.
 Pulverized coal in the power station. 1920. (In *Electrician*, v. 85, pp. 320-23, and continuation.)
 Table showing plant, equipment, overall costs and operating expenses per ton of coal, pulverized and burned. Cost of installation, machinery and equipment required, suitable fuels, pulverized coal vs. low-temperature carbonisation, coal samples, boiler efficiencies and the use of coke, various boilers, &c.
- ,, 241. JOHNSON, J. B.
 Modern coal-pulverizing plant at the United Verde. 1920. (In *Engng. Wld.*, v. 17, pp. 355-57.)
 United Verde Copper Co., after investigation, owing to increasing prices of fuel for reverberatory smelting installed a coal pulverizing plant and apparatus to burn it. Jeffrey breakers followed by Ruggles Coles driers and Raymond pulverizers. Powdered coal carried to smelter bins by screw conveyors and blown to drier burners with 40 lbs. air.
- ,, 242. KENTISH-RANKIN, I. L.
 Successful pulverized coal installation. 1920. (In *Power Plant Engng.*, v. 24, pp. 313-21.)
 Milwaukee Electric Railway and Light Co. shows excellent results after two years operation and several changes in furnace design. This is stated to be the largest installation of pulverized coal burning equipment under steam-raising boilers. Stations layout and coal movement. Furnace chamber. Boiler room instruments. Tests made, &c.
- ,, 243. KNOWLES, E. R.
 Pulverized fuel. 1920. (In *Jnl. Am. Soc. Heat and Vent. Engrs.*, v. 26, pp. 17-72.)
 Excerpts: *Steam*, v. 25, pp. 33-36, 63-68, 93-98.
 "Illustrates typical applications of pulverized fuel to heating furnace with waste heat boiler, to open-hearth furnaces, and arrangement of plant for pulverizing coal. Advantages and disadvantages of pulverized coal as fuel are discussed and figures are presented giving costs of coal-pulverizing plants and cost of pulverizing coal per ton." Many plans.
- ,, 244. KNOWLES, E. R.
 Pulverized fuel . . . why? 1920. (In *Combustion*, v. 3, pp. 18-23.)
 Summary of advantages of powdered coal. Tables of costs of plants and cost to pulverize a ton. How to eliminate high costs. Describes a small unit system—that is an apparatus that alone performs all the operations in preparing the coal and makes large, expensive apparatus unnecessary for a small power plant. Plans.
- ,, 245. Locomotive powdered fuel burning apparatus, Great Central Railway. 1920. (In *Ry. Rev.*, v. 66, pp. 410-11.)
 Details with drawings of an English locomotive.
- ,, 246. LONGENECKER, CHAS.
 Powdered coal winning out in special fields. 1920. (In *Coal Trd. Jnl.*, v. 51, pp. 353-55.)
 Advantages of increased efficiency in combustion and decreased labour costs recognized. Short account of apparatus. Explosion dangers overrated.

Ref. 247. MOLTYRE, O. L.

Pulverized coal in metallurgical furnaces at high altitudes. 1920. (In *Mech. Engng.*, v. 42, pp. 225-27. Also in *Min. and Met.*, v. 162, pp. 23-26; *Min. and Sci. Pr.*, v. 121, pp. 55-7; Excerpt in *Sci. Amer. Min.*, v. 1, pp. 479-80.)

Describes experiments in Peru at elevation of 14,000 ft. So successful that pulverized coal was put in use in blast furnaces, reverberatories and sintering machines. Shows method of determining the firing performance of pulverized coal, the behaviour of various mixtures, &c.

,, 248. MARSH, T. A.

Pulverized coal under boilers. 1920. (In *Elect. Ry. Jnl.*, v. 55, pp. 764-65.)

The writer believes that pulverized coal should not be burned in its raw state. By-products should be extracted and gas and coke burned. Doubts that raw pulverized coal is cheaper than stoker fired if all cost factors are considered.

,, 249. MATTHEW, H. T.

Burning powdered coal in a rolling mill. 1920. (In *Combustion*, v. 2, pp. 12-23.)

Newport Rolling Mill Co., Newport, Ky., has given up hand firing, stoker-firing and natural gas firing and adopted powdered coal for the entire plant. This article describes the milling plant, blowing tank unit, fuel transport lines, furnace bines, controllers, air supply, burners, &c. Illus.

,, 250. Melting iron with powdered coal. 1920. (In *Foundry*, v. 48, pp. 136-39. Also in *Iron Tr. Rev.*, v. 66, pp. 627-30.)

Small air furnace melting malleable iron is equipped with a system for burning powdered fuel. Comparison with hand-firing shows economy of new installation. Plans.

,, 251. MUHLEFELD, J. E.

Powdered coal. 1920. (In *Proceed. Engrs.' Soc. West. Penn.*, v. 3b, pp. 243-63, discussion 263-78. Abstract, *Blast Furnace and Steel Plant*, v. 8, pp. 527-31.)

Outline. General. Conditions justifying the use of powdered coal. Cost of installation. Cost of handling and preparing coal. Thermal efficiency. Combustion. Furnace and flue gas temperatures. Radiant heat. Non-combustible matter. Refractories. Upkeep. Human element. Cleanliness. Safety.

,, 252. MUIRHEAD, A. B.

Development in the use of low grade fuel at collieries. 1920. (In *Iron and Coal Trs. Rev.*, v. 101, pp. 33-34.)

Low grade fuel means fuel too poor for the market open to the particular colliery where mined. This may to a certain extent be used by the colliery itself. Discussion of the efficiency obtainable from these fuels. Suggestions for more extensive use of low grade fuels. Much of it is fine coal and may be used in ways indicated.

,, 253. New lakeside pulverized coal plant, Milwaukee. 1920. (In *Power*, v. 52, pp. 358-60.)

After three years successful operation of Oneida Street Plant with pulverized coal, the Milwaukee Electric Railway and Light Co. is now planning a new plant with initial installation of 40,000 K.w. Description of the chief features. Special coal handling equipment.

,, 254. Operating results with pulverized coal. 1920. (In *Elect. Rev.*, v. 76, p. 506.)

Oneida Street Station of Milwaukee Electrical Railway and Light Co. conducted a fire day test which is believed to be the most complete ever undertaken. A summary of the results are here given in tabular form.

- Ref. 255. ORROK, G. A.
 Some phases of the fuel problem. 1920. (In *Ser. Amer. Min.*, v. 1, pp. 426-28; see also *Steam*, v. 24, p. 21.)
 Relative advantages of oil and powdered coal. Graph shows comparative costs of coal and oil in heat equivalents.
- ,, 256. POMEROY, E. E. H.
 Coal-pulverizing plant at Nevada Consolidated Copper Smelter. 1920. (In *Min. and Met.*, No. 158, section 28, 10 p.)
 High price of oil made a change of fuel necessary. After an investigation the system of distributing pulverized coal here described was installed. After burning 170,000 tons the system has been called satisfactory. Illus.
- ,, 257. Powdered coal plant with compressed air transport. 1920. (In *Elect. Ry. Jnl.*, v. 55, pp. 817-18.)
 "Some details of the system that will be applied in the Mount Vernon St. plant of the Phila. Rapid Transit. Plan.
- ,, 258. Pulverized coal and its future. 1920. (In *Amer. Gas Engng. Jnl.*, v. 112, pp. 4-6.)
 "Pulverizing improves combustible quality of coal and permits more complete mixture of particles with the air obtaining perfect combustion with low percentage of excess air." Conditions requisite for successful use of pulverized coal. Advantages. Low grade fuels can be used. Cost of preparation. Method preparation. Ash dissipation.
- ,, 259. Pulverized coal burning equipment for Europe. 1920. (In *Ry. Mech. Engr.*, v. 94, pp. 581-82.)
 Description of locomotives recently designed to utilize low grade coals in Italy and Holland. Lignite coal in Italy—analyses.
- ,, 260. Pulverized coal for Italian locomotives. 1920. (In *Ry. Age*, v. 68, pp. 1363-64.)
 Illustrated description of equipment for Italian State Railways to use native low grade lignites.
- ,, 261. Pulverized coal for steam boilers. 1920. (In *Textile Wld. Jnl.*, v. 58, pp. 1523, 1525.)
 By pulverizing lower grade coal can be used. The finer the coal the greater the efficiency when burning if properly mixed with air. 95 per cent. should be ground small enough to pass through a 100 mesh screen. Advantages and disadvantages of using. Short description of the pulverizer and burners.
- ,, 262. Pulverized coal in a Milwaukee power plant. 1920. (In *Elect., Rev.*, v. 76, pp. 469-472.)
 Plant layout, methods and special features of Oneida Street Station of Milwaukee Electric Railway and Light Co. Details of equipment and sizes of motors used. Data on operating experiences. Plans.
- ,, 263. Pulverized coal in the malleable foundry. 1920. (In *Iron Age*, v. 105, pp. 259-61.)
 "Apparatus diffuses coal and air outside of furnace and uses low velocity jet. Nozzle design. Application to ovens."
- ,, 264. Pulverized coal versus stokers for boilers. 1920. (In *Iron Age*, v. 105, pp. 1798-1800; *Steam*, v. 26, pp. 40-42.)
 Comparison of equipment and operating costs. Factors to be considered in converting existing plant.
- ,, 265. Pulverized low-grade coals successfully employed. 1920. (In *Canad. Engr.*, v. 39, pp. 172-73.)
 "Comparative cost of pulverized coal installations. Upkeep. Favourable tests on wide variety of coals. Completeness of combustion. Ash problem.
- , 266. RAU, O. M.
 Pulverized fuel for peak-load service in railway power plants. 1920. (In *Power*, v. 52, pp. 140-141.)
 Pulverized coal found most economical by Phila. Rapid Transit Co.

- Ref. 267. SAVAGE, H. D.
 Powdered coal efficiencies. 1920. (In *Gas Age*, v. 45, pp. 541-43.)
 Consists largely of figures derived from tests of different coals.
- , 268. SAVAGE, H. D.
 Powdered fuel for chemical plants. 1920. (In *Combustion*, v. 3, pp. 32-33.)
 Powdered coal good in chemical plants as they require exact temperatures and pulverized coal by being easily controlled gives them.
- , 269. SAVAGE, HUGH.
 Le charbon pulvérisé. 1920. (In *Rev. Universelle des Mines de la Metallurgie des Travaux Publics*, Serie 6, Tome 6, pp. 5-48.)
 General survey of the use of pulverized coal. Tables of costs of installations for pulverizing. Drying, grinding. Account of many different systems for preparing and using pulverized coal with plans and illustrations. Use on locomotives and on ships. This article is apparently based to a considerable degree on the writings of L. C. Harvey which appear in this bibliography.
- , 270. SCHENDORFF, H.
 Four a souder chauffe au charbon pulvérisé au moyen d'u "Aero-pulvériseur." 1920. (In *Technique Moderne*, Année 12, pp. 81-82.)
 Welding furnace fired by pulverized coal by an "Aero" pulverizer. Description and operation of the "Aero" pulverizer. Some figures on the advantages of pulverized coal.
- , 271. SHADGEN, J. F.
 Methods of preparing pulverized coal. 1920. (In *Iron Age*, v. 105, pp. 389-92.)
 Descriptions of approved devices for crushing, pulverizing, drying, handling, cleaning, weighing and ventilating.
- , 272. SHADGEN, J. F.
 Pulverized coal distributing systems. 1920. (In *Iron Age*, v. 105, pp. 1423-26.)
 Coal powder and its characteristics. Storage and feeding devices. Pneumatic transportation by suspension, pressure and emulsion methods.
- , 273. SHADGEN, J. F.
 Science of powdered fuel combustion. 1920. (In *Iron Age*, v. 106, pp. 547-61.)
 Thermic fundamentals. Effects of various quantities on temperature and gas produced. The ash problem. Burner essentials.
- , 274. SHADGEN, J. F.
 Status of the powdered fuel problem. 1920. (In *Iron Age*, v. 105, pp. 32-34.)
 Principle of powdered coal combustion. History of the development. Fineness of grinding. Plea for establishing a factor of fineness.
- , 275. THOMPSON, P. W.
 Pulverized fuel at Oneida Street Plant. 1920. (In *Power*, v. 51, pp. 339-40. See also editorial pp. 341-42.)
 Short, rather general article about tests made by Milwaukee Electric Railway and Light Co. These tests are described in full in other articles in this bibliography, chiefly by John Anderson.
- , 276. TRINKS, W.
 Heating furnaces and annealing furnaces. 1920. (In *Blast Furnace and Steel Plant*, v. 8, pp. 288-89.)
 Powdered coal used. Effect of fineness of grinding upon successful operation of heating furnaces. Economical conditions for using powdered coal. Formula for powdered coal cost. Plans.
- , 279. Utilisation du combustible pulvérisé dans les foyers de locomotives. 1920. (In *La Technique Moderne*, Année 12, No. 2, Feb., pp. 83-84.)
 Use of pulverized fuel in locomotive furnaces on the Atchison, Topeka and Santa Fe R.R.

Ref. 280. VENANCOURT, G. DE.

Utilization du charbon pulvérisé au chauffage des fours à cuivre.
1920. (In *Rev. de Metallurgie*, Année 17, pp. 2-12.)

Use of pulverized coal in a copper smelting furnace. In particular is described the method and apparatus used by the Tennessee Copper Co. Plans of tuyeres, &c.

,, 281. Washery sludge burned in pulverized form at Seattle. 1920. (In *Power*, v. 51, pp. 729-31.)

Coal-preparation plant. Raw-coal handling system. Drying plant. Pulverizing plant. Combustion equipment. Operation. Results have been very successful.

,, 282. WELLES, E. R. and JACOBI, W. H.

Powdered coal as a fuel for boiler. 1920. (In *Stevens Indicator*, v. 37, pp. 97-125; *Steam*, v. 26, pp. 63-68 and continued.)

Advantages of pulverized coal. Cost compared to lump. Burners and furnaces.

,, 277. WOOD, W. D.

Pulverized coal installation on the Lehigh Valley R.R. 1920. (In *Ry. Rev.*, v. 66, pp. 1013-14.)

"Account of the performance of a locomotive equipped to utilize a combination of bituminous and anthracite coal in the pulverized form." This engine has been doing more than rated for five months.

,, 283. WOTHERSPOON, W. L.

Progress in the use of pulverized fuel in blast furnaces. 1920. (In *Iron and Steel of Canada*, v. 3, pp. 5-8. See also *Engng. and Min. Jnl.*, v. 109, pp. 803-04.)

Description of Vortex tuyeres and its adaptation of form a small combustion chamber. Detailed drawings. Midvale lead smelter is using powdered coal.

SOME PAPERS AND ARTICLES ON PULVERISED COAL.

(By the Author).

Paper. FUEL ECONOMY POSSIBILITIES IN BRASS MELTING FURNACES.

The Institute of Metals, London, September, 1917.

,, THE USE OF PULVERISED COAL.

Iron and Steel Institute—London—Meeting, May, 1919. (Comparison Paper to the Fuel Research Board Report.)

,, THE USE OF COMBUSTION INSTRUMENTS and NOTES ON PULVERISED COAL APPLICATIONS in the TEXTILE INDUSTRY.

The Association of Managers of Textile Factories, Manchester, 1919.

,, SOME NOTES ON PULVERISED COAL PLANT.

Staffordshire Iron and Steel Institute, December, 1919.

Article. SOME GENERAL CONSIDERATIONS in REGARD to the USE OF POWDERED COAL FOR FIRING BOILER PLANTS.

"The Electrician," June 27th, 1919.

,, PULVERISED COAL IN THE POWER STATION (L. C. Harvey and E. E. Noble).

"The Electrician," September 17th and October 1st, 1920.

,, NATIONAL COAL STATISTICS as affected by the USE OF PULVERISED COAL.

"The Power User," September, 1919.

,, LES APPLICATIONS DU CHARBON PULVÉRISÉ AU POINT DE VUE DE L'ÉCONOMIE NATIONALE.

Europäische Wirtschafts-Zeitung. (Journal Economique Européen), October 2nd, 1920.

,, THE USE OF PULVERISED COAL ON RAILWAYS.

"Railway Gazette," September 5th, 1919.

- Article. PULVERISED COAL EQUIPMENTS FOR RAILWAY LOOMOTIVES.
" Railway Engineer," July, 1920.
- „ L'EMPLOI DU CHARBON PULVÉRULENT SUR LES LOOMOTIVES.
(*Reprint.) Bulletin of the International Railway Association, July-
September, 1919.
- „ THE APPLICATION OF PULVERISED COAL and COLLOIDAL OIL to MARINE
BOILERS.
" The Shipbuilder," November, 1919.
- „ PULVERISED COAL IN THE BRASS FOUNDRY.
" The Metal Industry," September 19th, 1919.

FUEL RESEARCH BOARD—(contd.)

		Price s. net d.	With postage s. d.
Report of the Fuel Research Board for the years 1920, 1921. First Section: Steaming in Vertical Gas Retorts		1 6	1 8
A Handbook on the Winning and Utilisation of Peat, by A. Hausding. (<i>Translated from the third German edition</i>)	(In preparation)		

SPECIAL REPORTS:—

No. 2. The Peat Resources of Ireland. A lecture given before the Royal Dublin Society, on 5th March, 1919, by Professor Pierce F. Purcell, Assoc. M.Inst.C.E. 1920 ...	0 9	0 10½
No. 3. "The Coal Fire." (<i>An investigation into the efficiency of open fires</i>), by Margaret White Fishenden, D.Sc. 1920 ...	4 0	4 2½

TECHNICAL PAPERS:—

No. 1. The Assay of Coal for Carbonisation Purposes. A new laboratory method, by Thomas Gray, D.Sc., Ph.D., and James G. King, F.I.C., A.R.T.C. 1921 ...	0 6	0 7
No. 2. Report on the Simmance Total Heat Recording Calorimeter, by Thomas Gray, D.Sc., Ph.D., and Alfred Blackie, M.A. 1921 ...	0 9	0 10½
No. 3. The Efficiency of Low Temperature Coke in Domestic Appliances, by Margaret White Fishenden, D.Sc.	0 9	0 10½
No. 4. The Carbonisation of Peat in Vertical Gas Retorts. 1921	0 6	0 7

MISCELLANEOUS REPORTS, ETC.:—

Lubricants and Lubrication Inquiry Committee, Final Report of. 1920	2 6	2 9½
Monograph on the Constitution of Coal, by Marie C. Stopes, D.Sc., Ph.D., and R. V. Wheeler, D.Sc. (<i>With plates.</i>) 1918	2 0	2 2

